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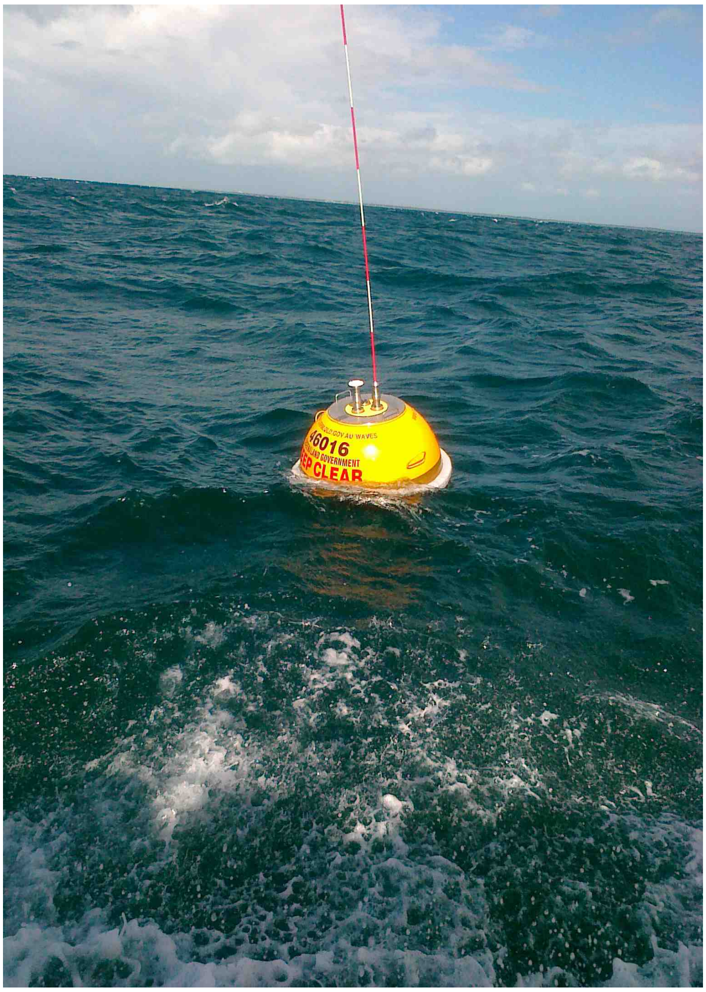

Queensland Wave Climate

Wave Monitoring Annual Summary

November 2014 to October 2015

Coastal Impacts Unit, DSITI

Queensland Government

Prepared by

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Daryl Metters, Robert Wall, Paul Pinjuh and Linda Rijkenberg

August 2016

Executive Summary

This summary of wave climate in Queensland is prepared annually by the Coastal Impacts Unit (CIU) of 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 2014 to 31 October 2015.

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 operated at all sites, except Cairns, where a non-directional Waverider buoy is deployed due to the sheltered nature of the site. The directional buoys also record temperature in the bottom of the hull; the temperature record is called Sea Surface Temperature (SST) here.

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

The data covers all of the seasonal variations for one year, and includes the 2014–5 cyclone season, which extends from 01 November through to 30 April. This period is also classed as summer while the remainder of the year 01 May to 31 October, is classed as winter in these reports.

Figure 3 graphically illustrates each of the cyclone tracks and intensities during the 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.

There were three tropical cyclones that moved close to the Queensland coast during the reporting period. Tropical cyclones Lam, Marcia and Nathan made landfall on the coast, briefly passed close to the central Queensland coast.

Tropical cyclone (TC) Lam made landfall as a tropical low pressure system then moved across Cape York Peninsular before developing into a tropical cyclone in the Gulf of Carpentaria. Tropical Cyclone Lam developed further into a category four severe tropical cyclone before making a second landfall on the Northern Territory coast (DSITI 2015b). No top ten wave heights were reported during the passage of TC Lam.

Tropical cyclone Marcia made landfall on 20 February 2015 at Shoalwater Bay as a category five severe tropical cyclone (DSITI 2015). A record highest Hsig of 4.0 m and a Hmax of 7 m ranked third was seen at Emu Park. This record is impressive considering the 20 years of wave buoy operation at Emu Park.

During March tropical cyclone Nathan meandered around the north east coast and crossed the Cape York Peninsular as a category four severe tropical cyclone on 20 March 2015 (DSITI, 2015a). A Hmax of 2.9 m did not rank in the top ten wave records at Cairns.

Contents

1 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 Science, Information Technology and Innovation (DSITI). Annual wave reports supplement the reporting ability of DSITI'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 2014 to 31 October 2015.

The data covers all of the seasonal variations for one year, and includes the 2013–14 cyclone season, which extends from 01 November through to 30 April. This period is also classed as 'summer' while the remainder of the year (01 May to 31 October) is classed as 'winter' in these reports. For all stations, the wave data collected for the current year is statistically compared to the long-term average conditions at the site. Brief details of the recording equipment, the methods of handling raw data and the type of analyses employed are provided within this report.

2 Wave monitoring sites

As part of its long-term data collection program, DSITI 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 DSITI.

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 DSITI in conjunction with (and jointly-funded by) partner agencies.

Table 1 Wave recording stations November 2014 to October 2015

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

	Hay Point	North Queensland Bulk Ports
	Abbot Point	North Queensland Bulk Ports
	Albatross Bay (Weipa)	North Queensland Bulk Ports

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

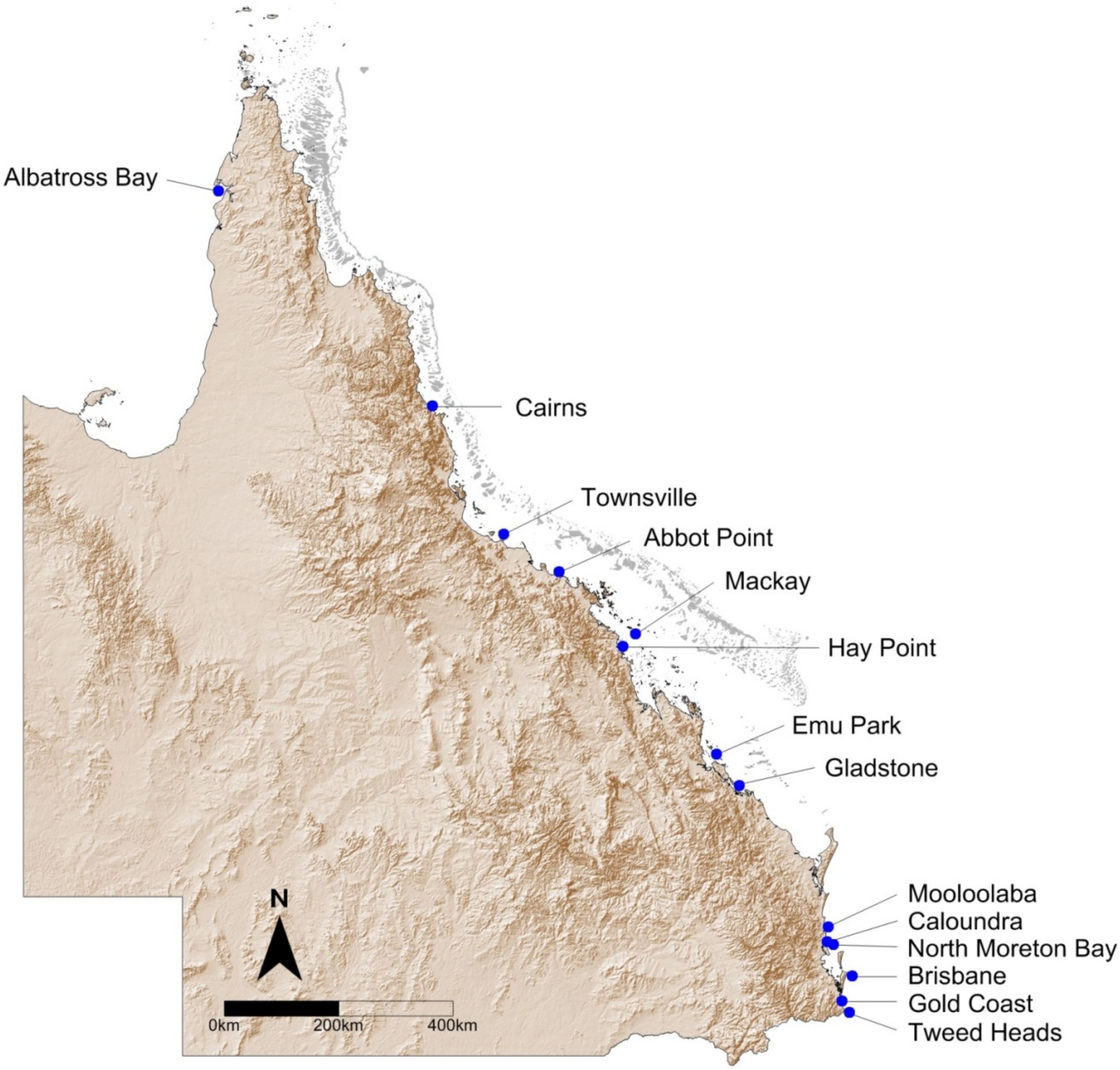


Figure 1 DSITI wave monitoring sites in Queensland

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	20.8	20.8
Gold Coast	21/03/1987	-	-	17/07/2007	28.6	8.3
Brisbane	31/10/1976	-	-	20/01/1997	39.0	18.8
Caloundra	01/05/2013	-	-	01/05/2013	2.5	2.5
North Moreton Bay	08/03/2010	-	-	08/03/2010	5.7	5.7
Mooloolaba	20/04/2000	-	-	11/05/2005	15.5	10.5
Gladstone	23/09/2009	-	-	23/09/2009	6.1	6.1
Emu Park	24/07/1996	-	-	24/07/1996	19.3	19.3
Hay Point	24/04/1977	25/05/1987	3/04/1993	31/10/2009	32.7	6.0
Mackay	19/09/1975	-	-	13/03/2002	40.1	13.6
Abbot Point	17/01/2012	-	-	17/01/2012	3.8	3.8
Townsville	20/11/1975	-	-	29/10/2008	40.1	7.0
Cairns	04/05/1975	-	-	-	40.5	0.0
Albatross Bay (Weipa)	22/12/1978	-	-	25/11/2008	36.9	6.9

2.1 Wave monitoring equipment

For the monitoring period documented in this summary report DSITI'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 Cairns due to the sheltered nature of the site limiting wave direction.

2.2 Accelerometer Buoys

The directional Waverider buoys at the Brisbane, 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).

2.3 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.

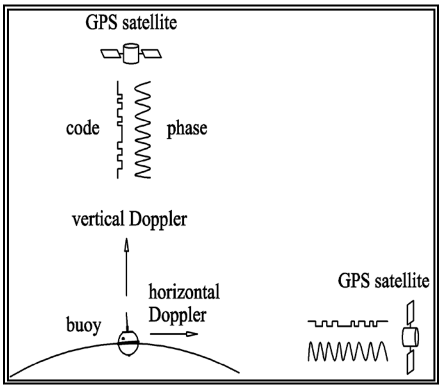


Figure 2 The GPS wave measurement principle (Datawell, 2010)

3 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.

4 Quality checks

Waverider buoys used by DSITI are calibrated before deployment and after recovery. Generally a buoy is calibrated every 12 months. Accelerometer buoys are calibrated at DSITI's Deagon site using a buoy calibrator to simulate sinusoidal waves with vertical displacements of 2.7 meters. 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.

4.1 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.

5 Data analysis

The computer-based, wave-recording systems at all sites record data at half-hourly intervals. Raw data transmitted from the buoys is 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 Hz. 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 Hz. 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.

6 Major Meteorological events

Table 4 Tropical Cyclones in the Queensland region during the 2014–2015 season

Name	Start Time (AEDT)	End Time (AEDT)	Category	Central Pressure (hPa)
Lam	13/02/2015	20/03/2015 07:00	4	951
Marcia	18/02/2015	20/02/2015 09:00	5	929
Nathan	08/03/2015	23/03/2015 18:00	4	963

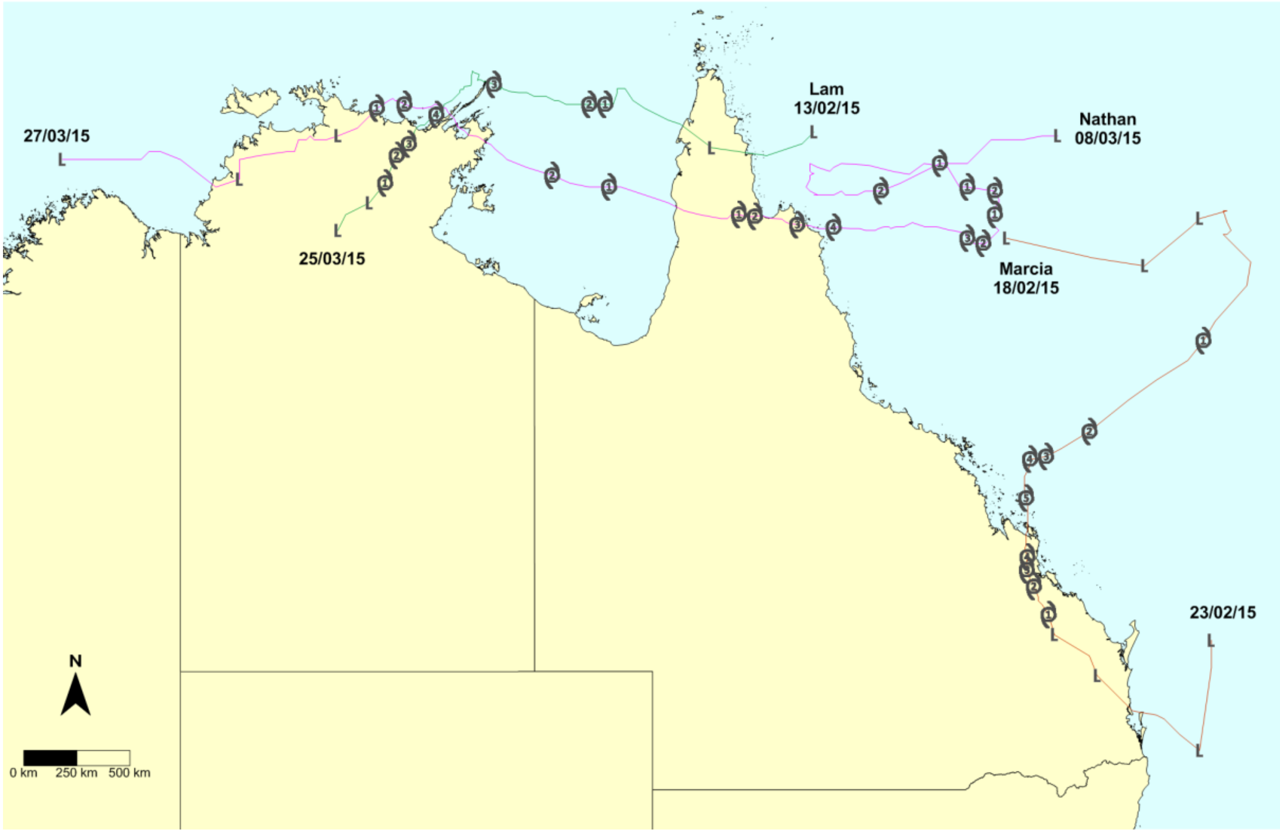


Figure 3 Tropical cyclones affecting Queensland coastline during the 2014–2015 season

7 Queensland wave climate

7.1 Tweed Heads

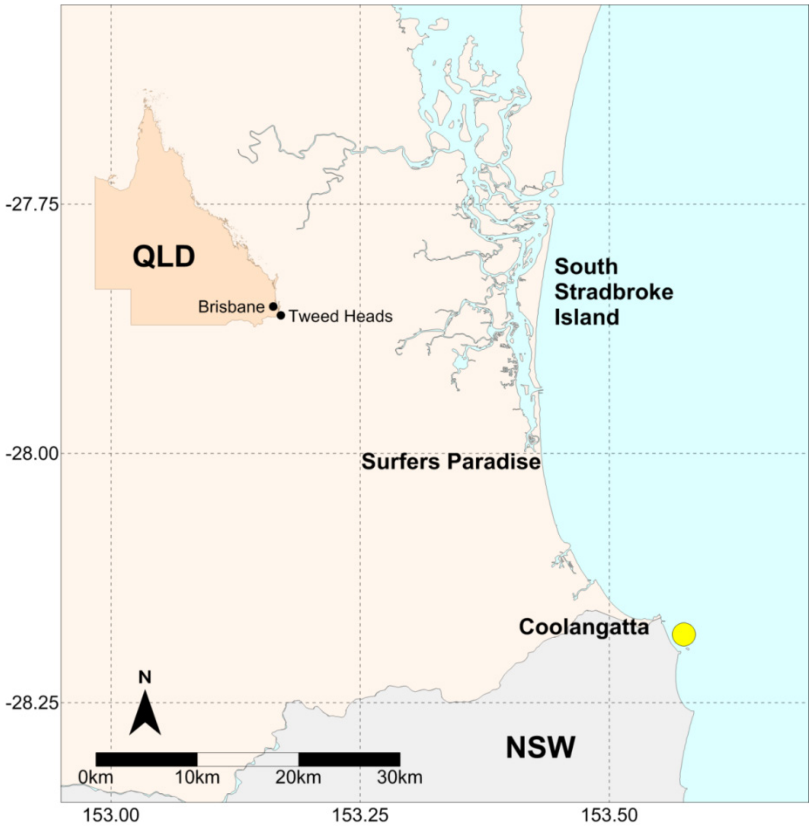


Figure 4 Tweed Heads – Locality plan

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	308,324	20.8
2014–15	01/11/2014	2.54 days	17,397	1

Table 6 Tweed Heads – Buoy deployments during the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
28°10.910' S	153°34.555' E	22	17/04/2014	17/04/2015
28°10.870' S	153°34.485' E	20	17/04/2015	current

7.1.1 Tweed Heads – seasonal overview

The Tweed Heads wave buoy has been operational for nearly 21 years with an overall data return of 98.5 per cent. The data recorded for the period November 2014 to October 2015 was excellent, with total gaps of only 2.54 days, equivalent to 99.4 per cent data return. The buoy was replaced once during the reporting period on 17 April 2015 (Table 6).

From the 18 February, TC Marcia tracked south from central Queensland to eventually deteriorate into a low pressure system off the southeast Queensland coast. This system generated a significant wave height (Hsig) of 3.5 m and a maximum wave height (Hmax) of 6.6 m on 22 February. The largest waves generated during the reporting period were from an East Coast Low north of Fraser Island on 01 May. This ranked at fifth for the highest wave recordings at Tweed Heads (Table 7) with a Hsig of 5.5 m and Hmax of 9.0 metres.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 19°C to 28°C (Figure 6). The SST from January through to the early April was intermittently 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 March and July where the mean was less than -1 sd, as well as February which was greater than +1 sd due to the extended influence of TC Marcia (see DSITI 2015).

The wave heights during the reporting period were similar to the wave height of the whole record with the exception of the summer period where wave heights greater than two metres were less frequent and wave height less than one metre were more frequent, as shown in the percentage exceedance (Figure 8). Histograms of the occurrence of Hsig (Figure 9) show a higher mode and a more narrow spread for the reporting period compared to the overall record across both summer and winter months. 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 the recent 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 winter 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	3/05/1996 01:00	7.5	2/05/1996 14:30	13.1
2	28/01/2013 08:30	6.7	28/01/2013 09:00	11.8
3	6/03/2004 01:00	6.1	5/03/2004 23:30	11.1
4	21/05/2009 19:30	5.6	30/06/2005 06:30	9.9

5	1/05/2015 22:30	5.5	22/05/2009 07:00	9.7
6	24/05/1999 05:00	5.2	4/03/2006 12:00	9.6
7	4/03/2006 20:30	5.2	25/03/1998 22:30	9.5
8	12/06/2012 10:00	5.2	15/02/1995 15:30	9.3
9	15/02/1995 11:30	5.2	12/06/2012 11:30	9.3
10	30/06/2005 09:00	4.9	2/02/2001 02:00	9.1

Table 8 Tweed Heads – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
23/01/2015 09:00	2.6 (2.7)	4.5 (5.1)	10.5	From 21 January severe thunderstorms impacted the central Queensland coast with a trough extending along the eastern coastline resulting in thunderstorms on 23 January in southeast Queensland.
22/02/2015 17:00	3.1 (3.5)	5.3 (6.6)	10.1	TC Marcia formed on 18 February off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate in to a low off the southeast Queensland coast.
1/05/2015 22:30	5.1 (5.5)	8.0 (9.0)	10.9	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast 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.

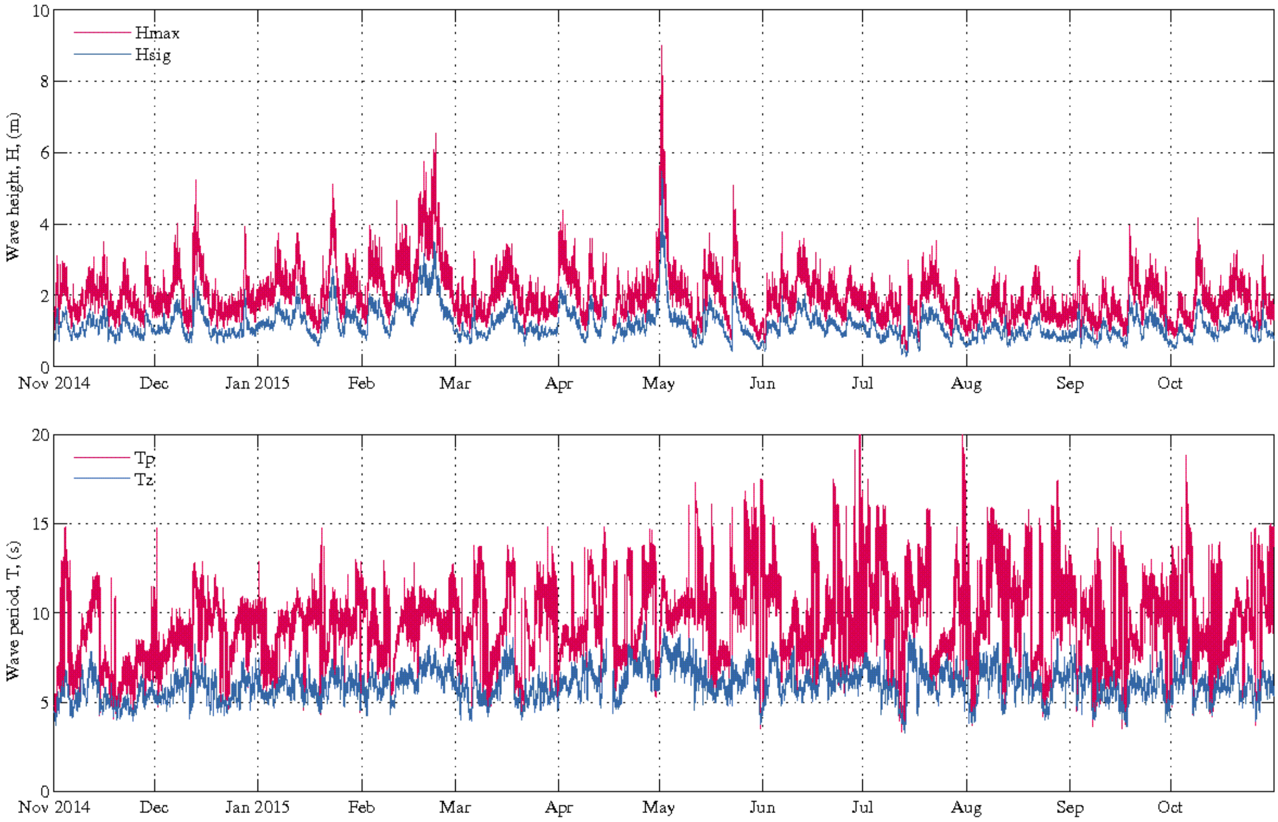


Figure 5 Tweed Heads – Daily wave recordings

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

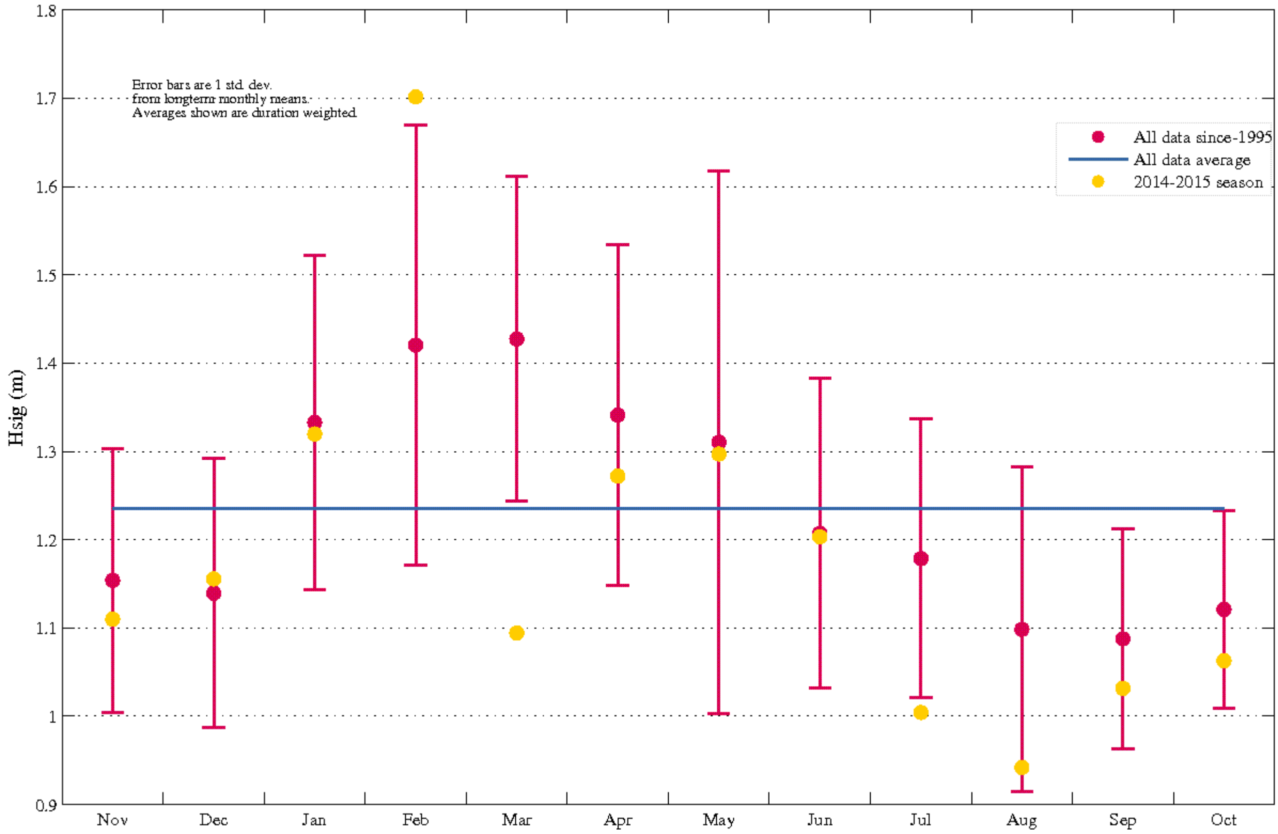


Figure 7 Tweed Heads – Monthly average wave height (Hsig) for seasonal year and for all data

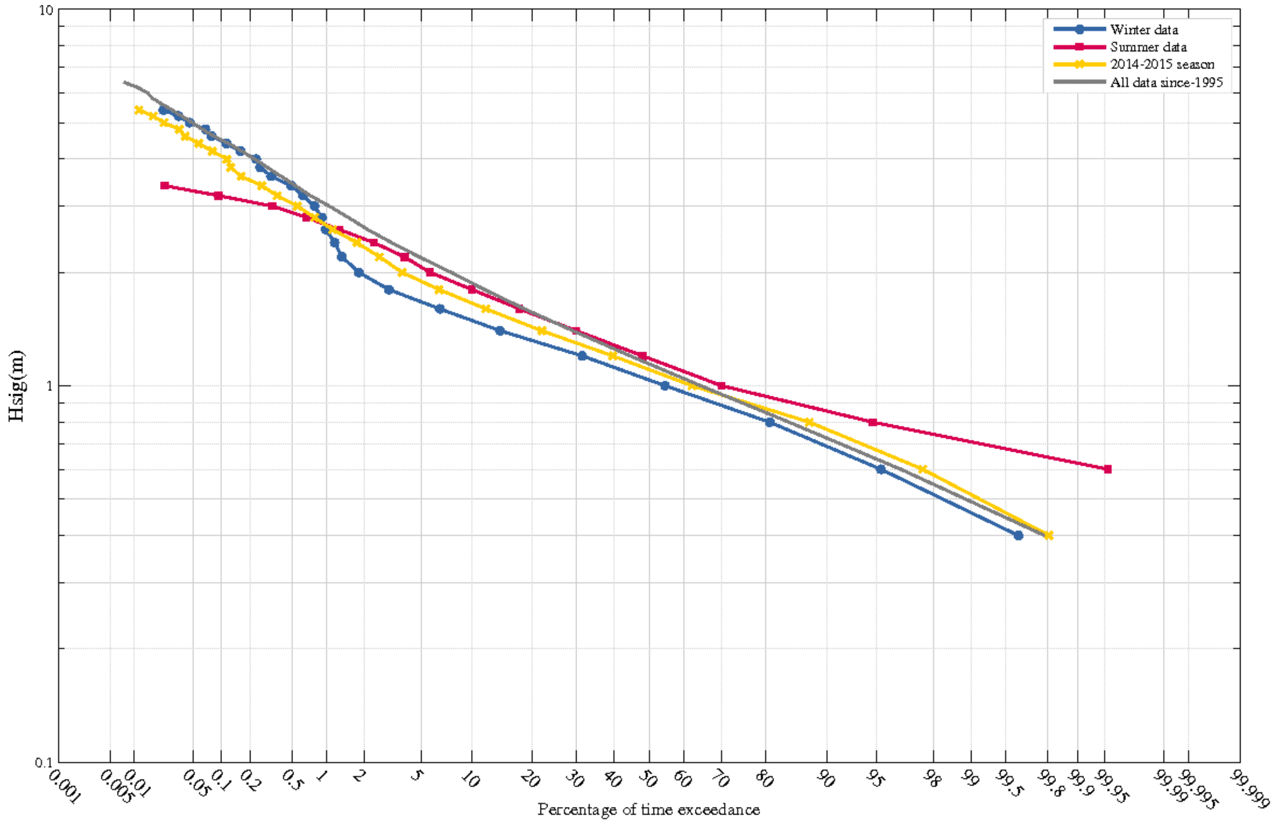


Figure 8 Tweed Heads – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

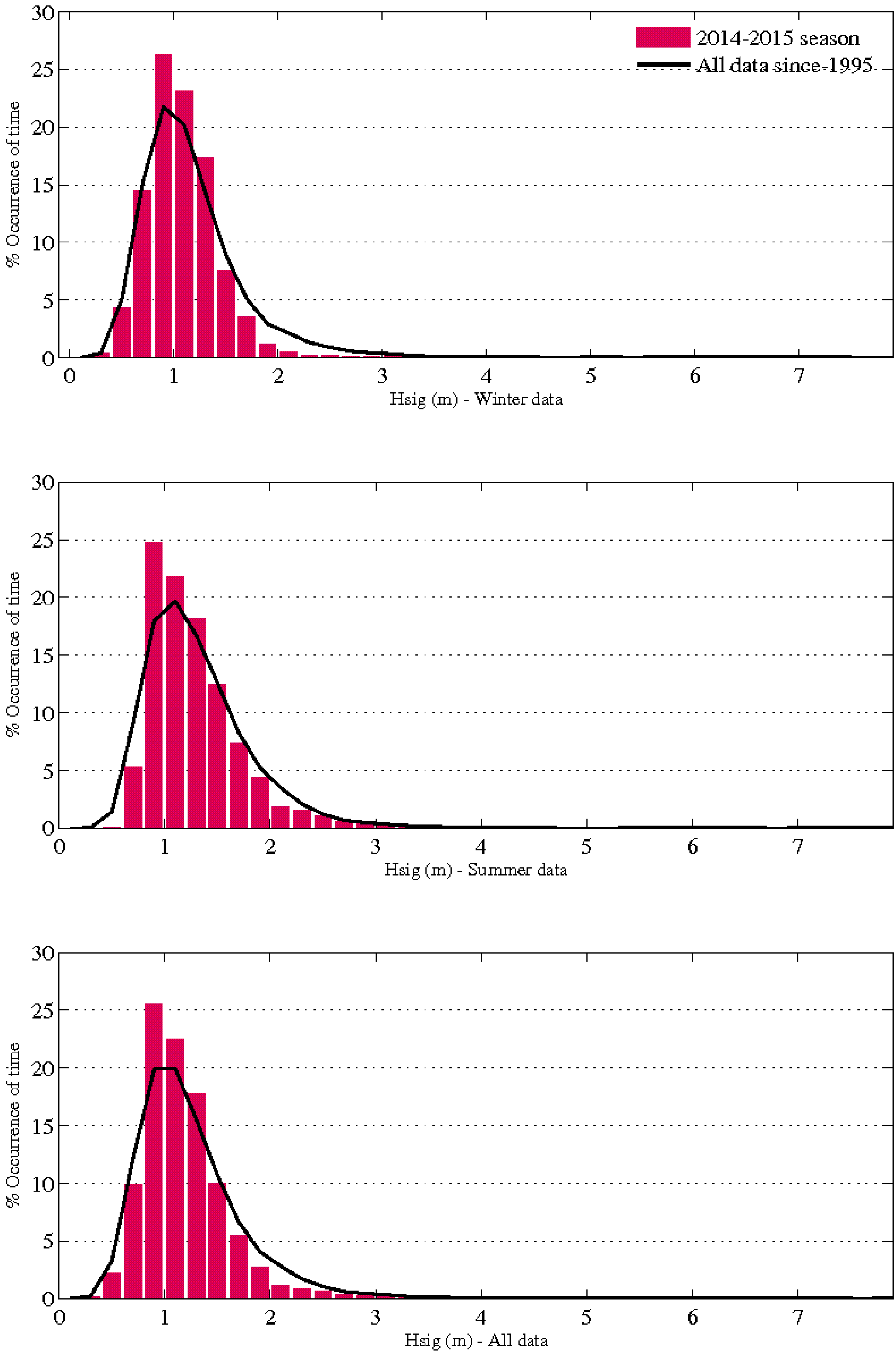


Figure 9 Tweed Heads – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

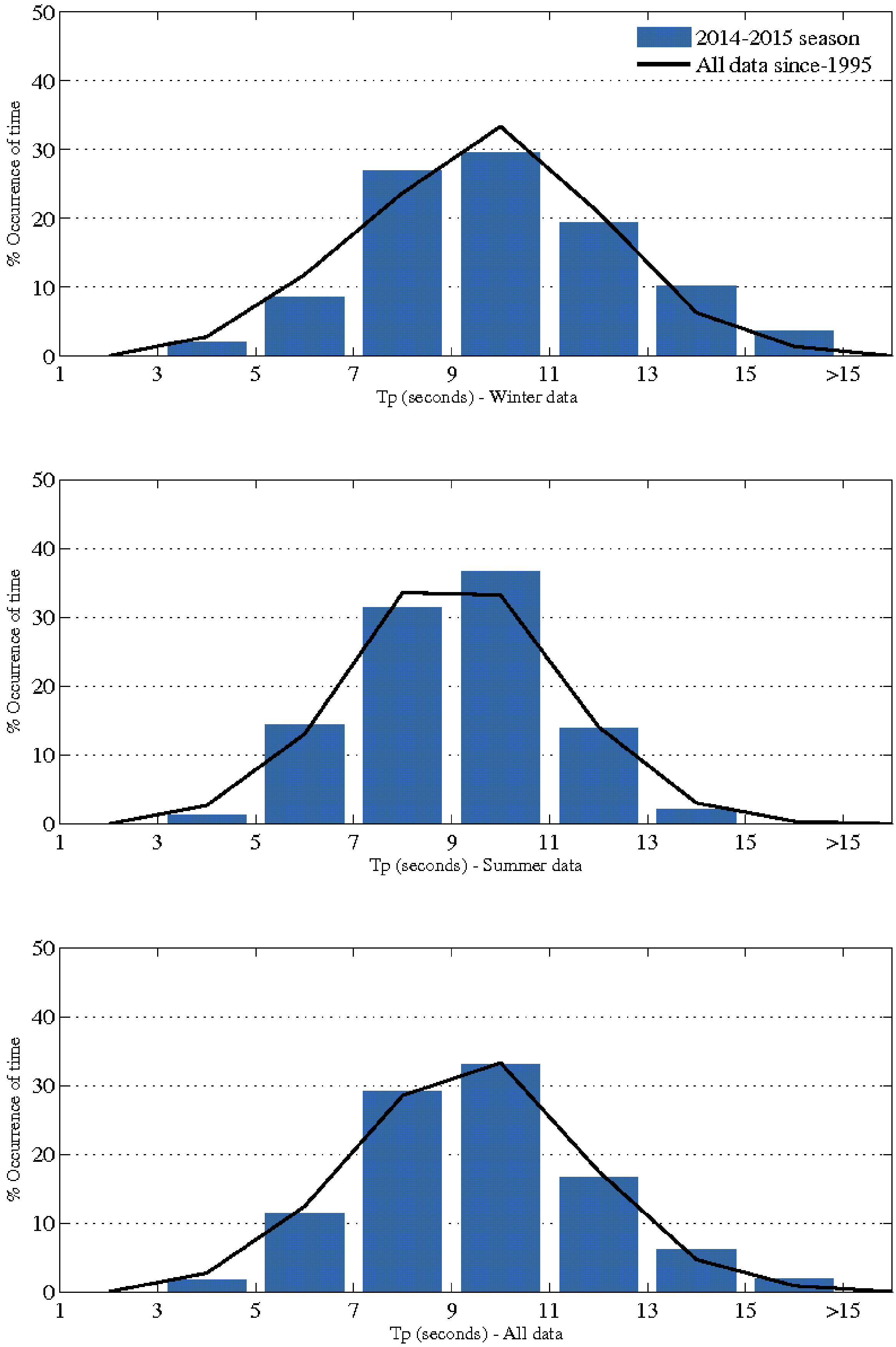


Figure 10 Tweed Heads – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

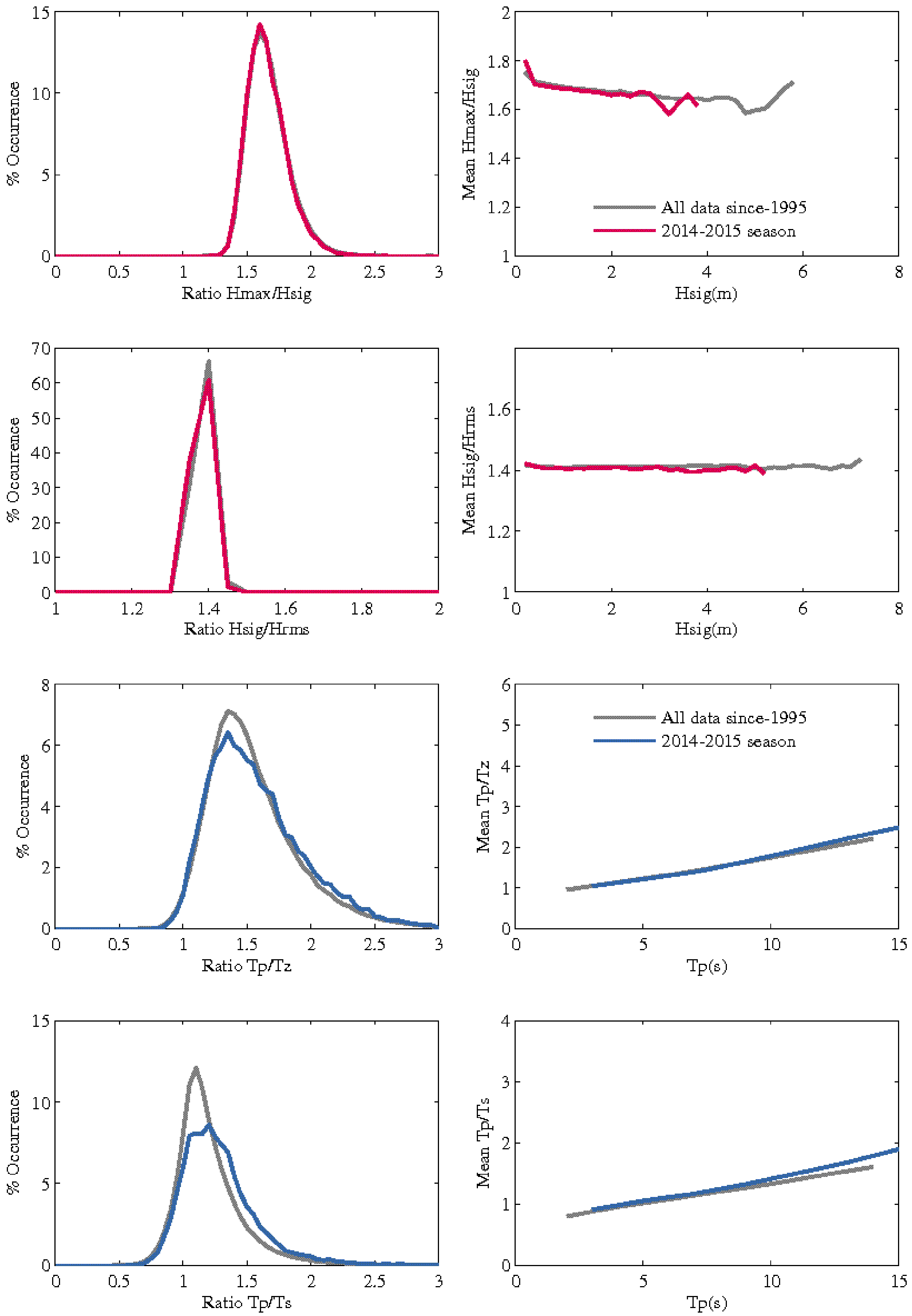
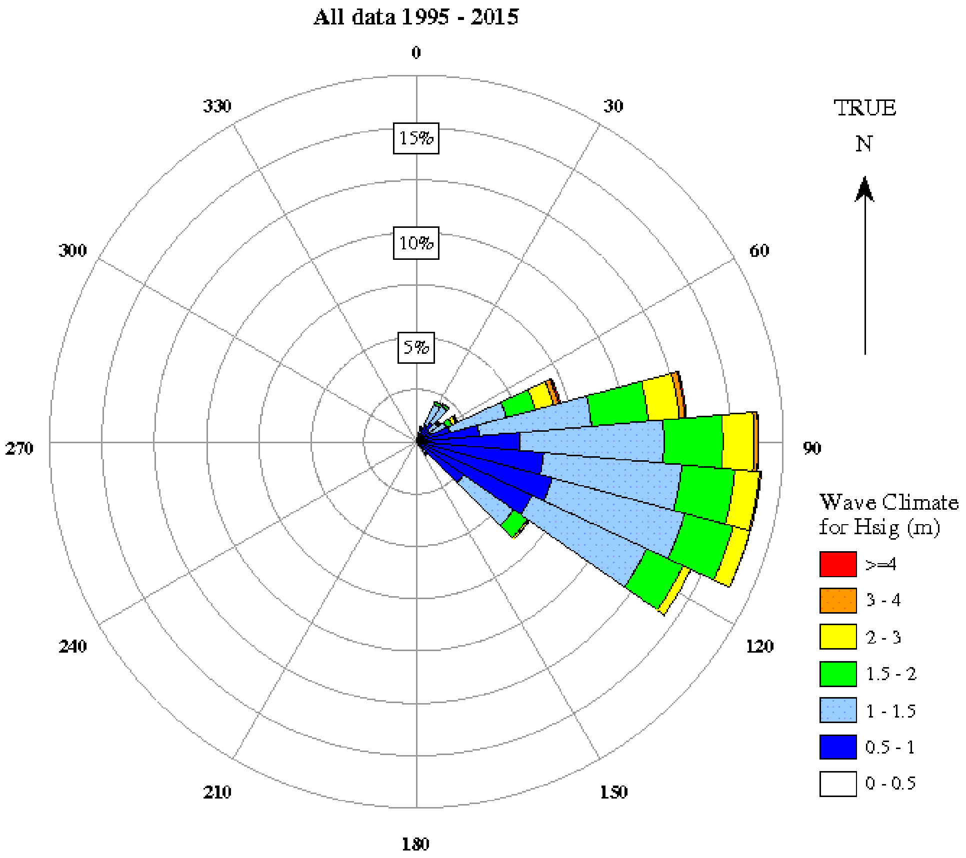


Figure 11 Tweed Heads – Wave parameter relationships



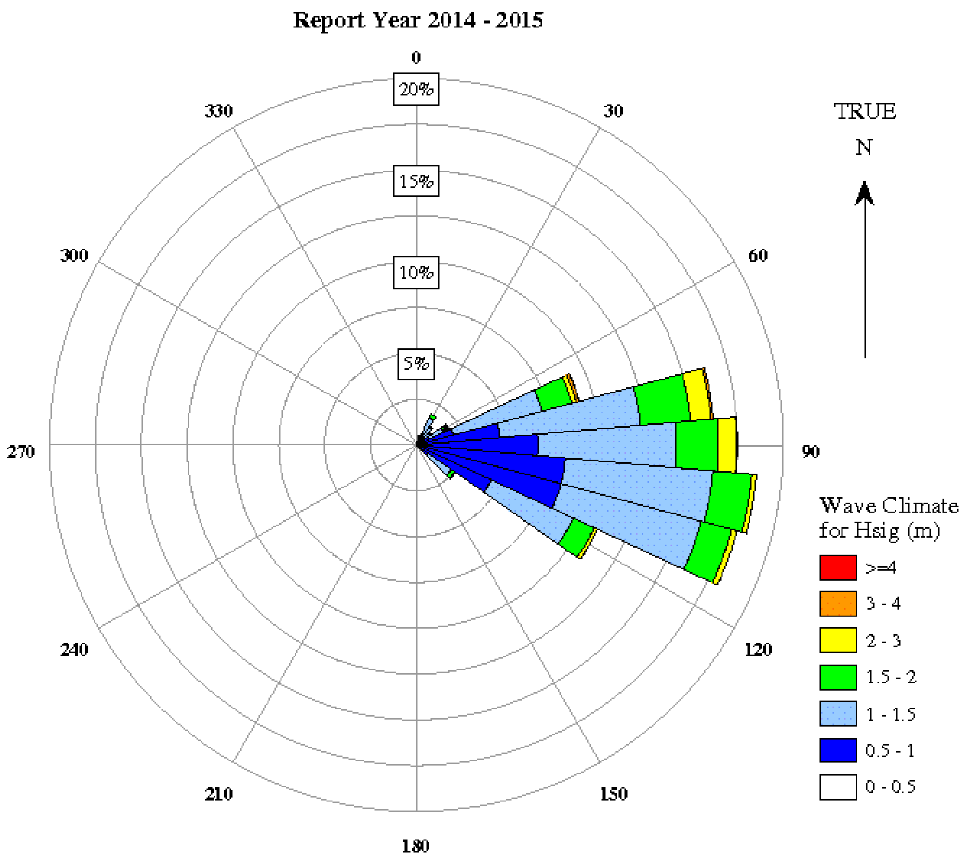


Figure 12 Tweed Heads – Directional wave rose

7.2 Gold Coast

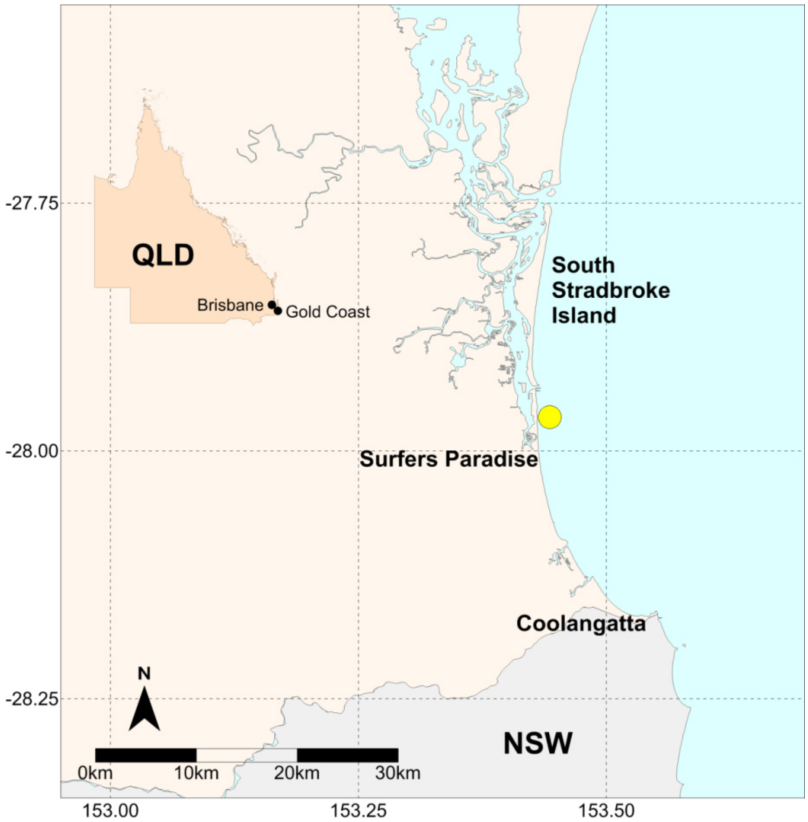


Figure 13 Gold Coast – Locality plan

Table 9 Gold Coast – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	21/03/1987	3.39 years	338,139	28.7
2014–15	01/11/2014	0.7 days	17,486	1

Table 10 Gold Coast – Buoy deployments during the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
27°57.980'S	153°26.530'E	17	04/10/2014	current

7.2.1 Gold Coast – seasonal overview

The Gold Coast wave buoy has been operational for over 28 years with an overall data return of 88.2 per cent. The data recorded for the period November 2014 to October 2015 was exceptional, with total gaps of only 0.7 days, equivalent to 99.8 percent data return. The buoy was not replaced during the reporting period.

TC Marcia influenced the Gold Coast as it tracked south from central Queensland from 18 February and deteriorated in to a low off the southeast Queensland coast generating a significant wave height (Hsig) of 3.7 m and maximum wave height (Hmax) of 6.8 m on 23 February. The largest waves for the reporting period occurred on 01 May from an East Coast Low which developed north of Fraser Island. This ranked at tenth for the highest wave recordings at the Gold Coast (Table 11) with a Hsig of 5.0 m and Hmax of 8.9 metres. 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 28° C (Figure 15). The SST from mid-December to the end of March was intermittently 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 except for a +1 sd exceedance during February and a -1 sd exceedance during March. The exceedance in February is due to the extended increase in wave heights generated by TC Marcia (see DSITI 2015).

The wave climate during the reporting period was similar to the wave climate of the whole record, 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 significantly greater occurrence of the modal 0.8–1.0 m Hsig waves during summer for the reporting period compared to the record. This resulted in a higher peaked distribution for waves in the recent reporting period. 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 around 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 20.

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	15/02/1995 07:00	5.0	15/02/1995 10:30	9.2
10	01/05/2015 21:00	5.0	02/04/2009 05:30	9.0

Table 12 Gold Coast – Significant meteorological events with threshold Hsig of 3 metres.

Date	Hs (m)	Hmax (m)	Tp (s)	Event
23/02/2015 01:00	3.4 (3.7)	5.7 (6.8)	10.5	TC Marcia formed on 18 February off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate into a low off the southeast Queensland coast.
01/05/2015 21:00	4.5 (5.0)	7.2 (8.9)	10.9	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast 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.

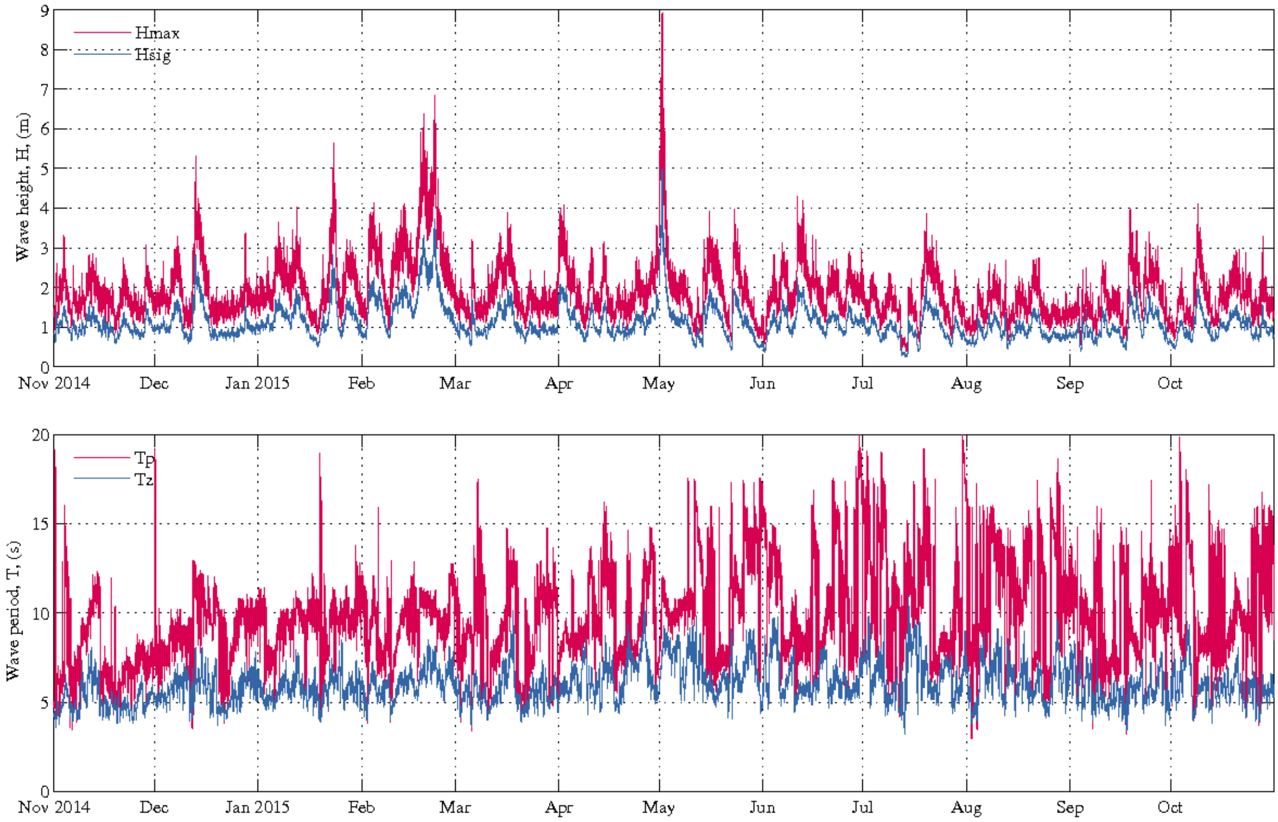


Figure 14 Gold Coast – Daily wave recordings

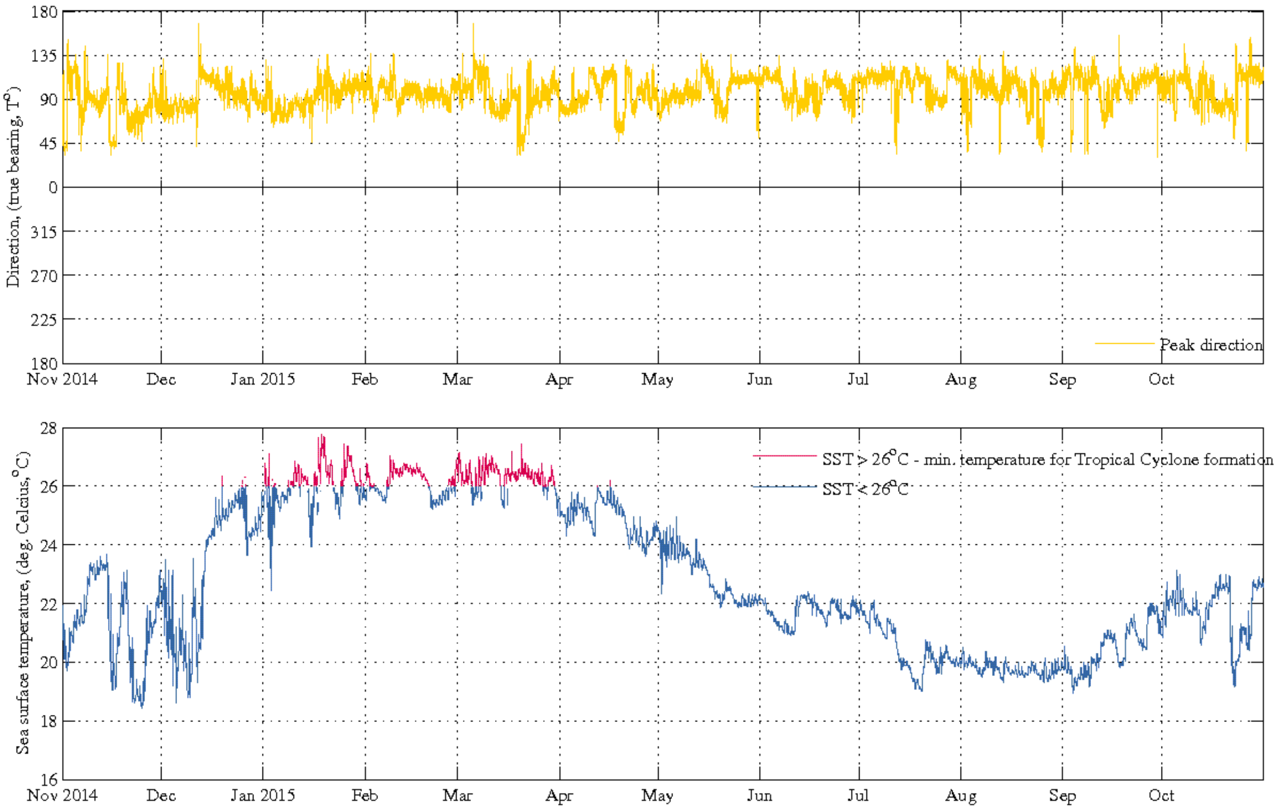


Figure 15 Gold Coast – Sea surface temperature and peak wave directions

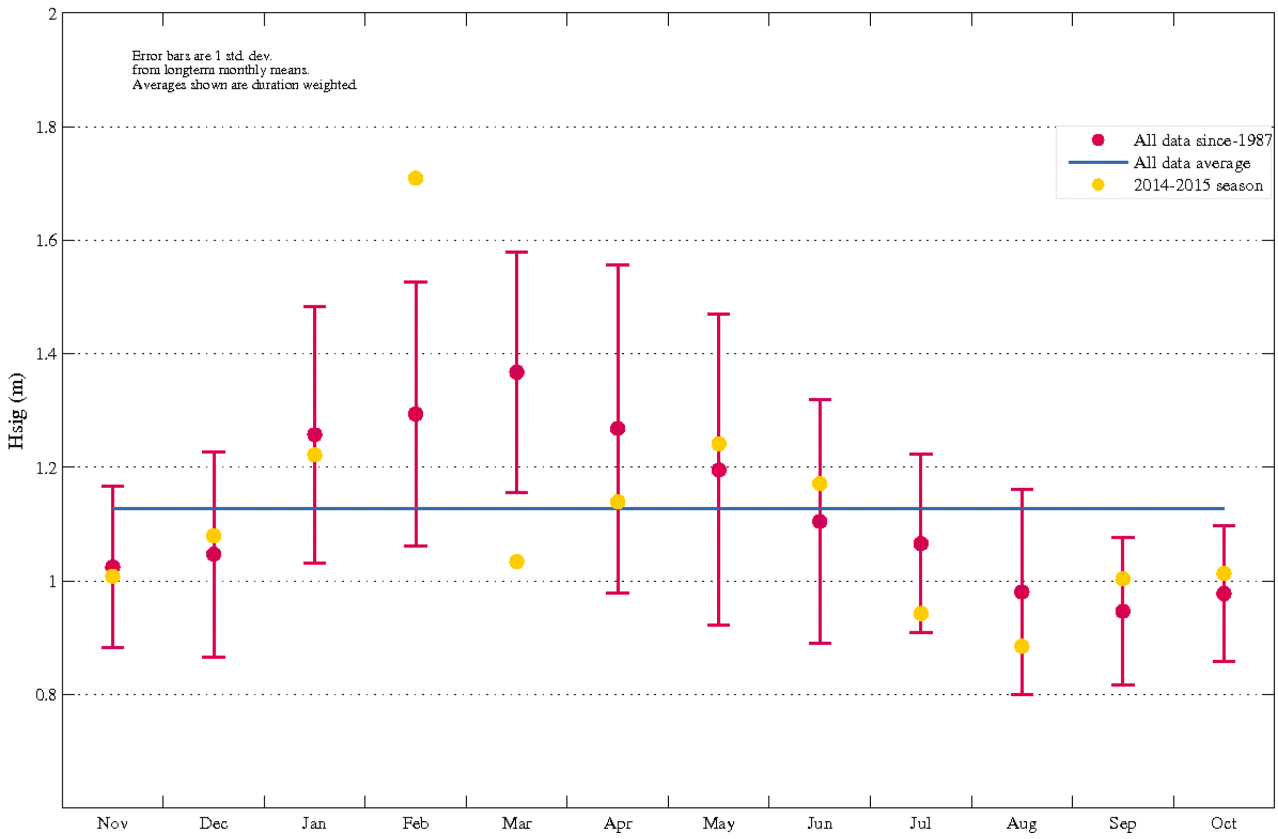


Figure 16 Gold Coast – Monthly average wave height (Hsig) for seasonal year and for all data

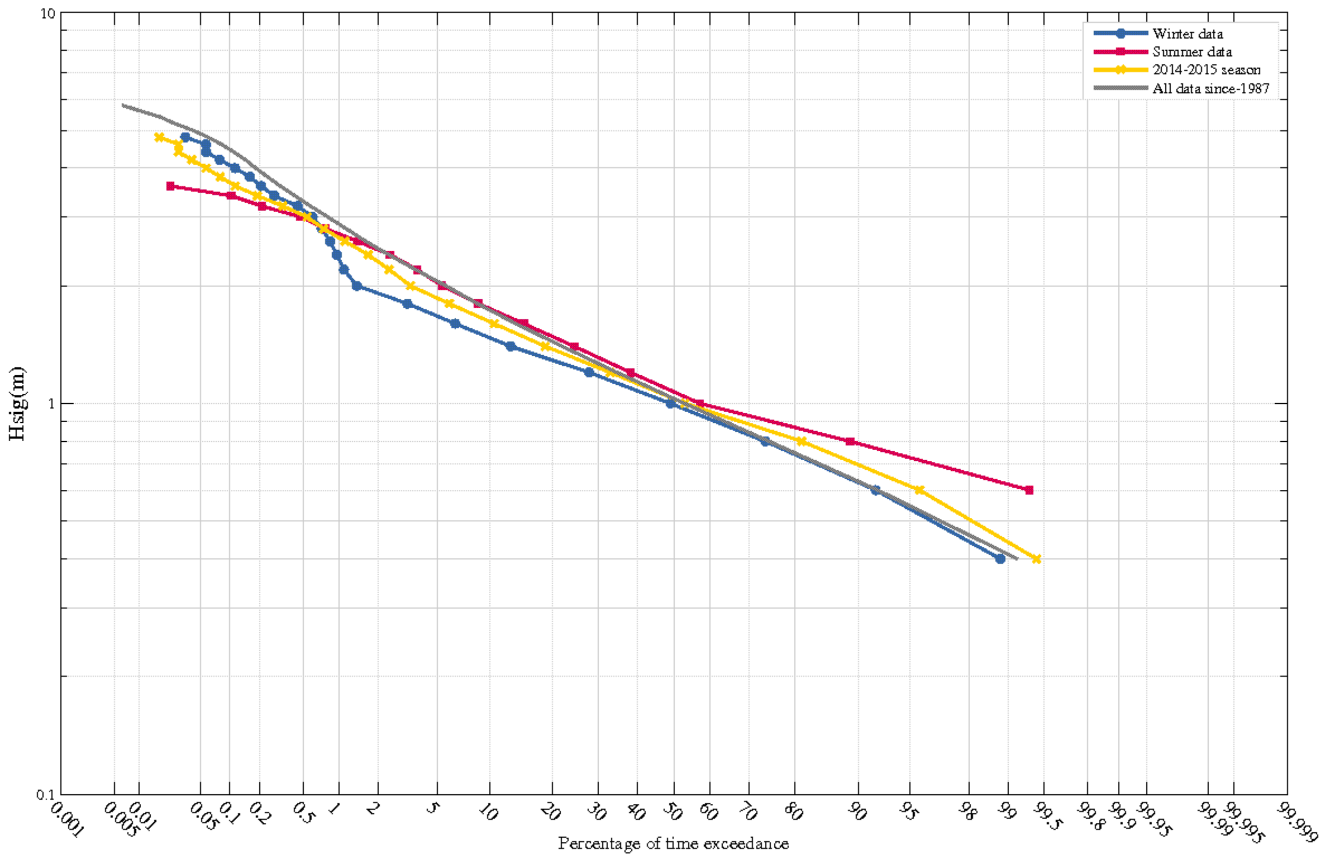


Figure 17 Gold Coast – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

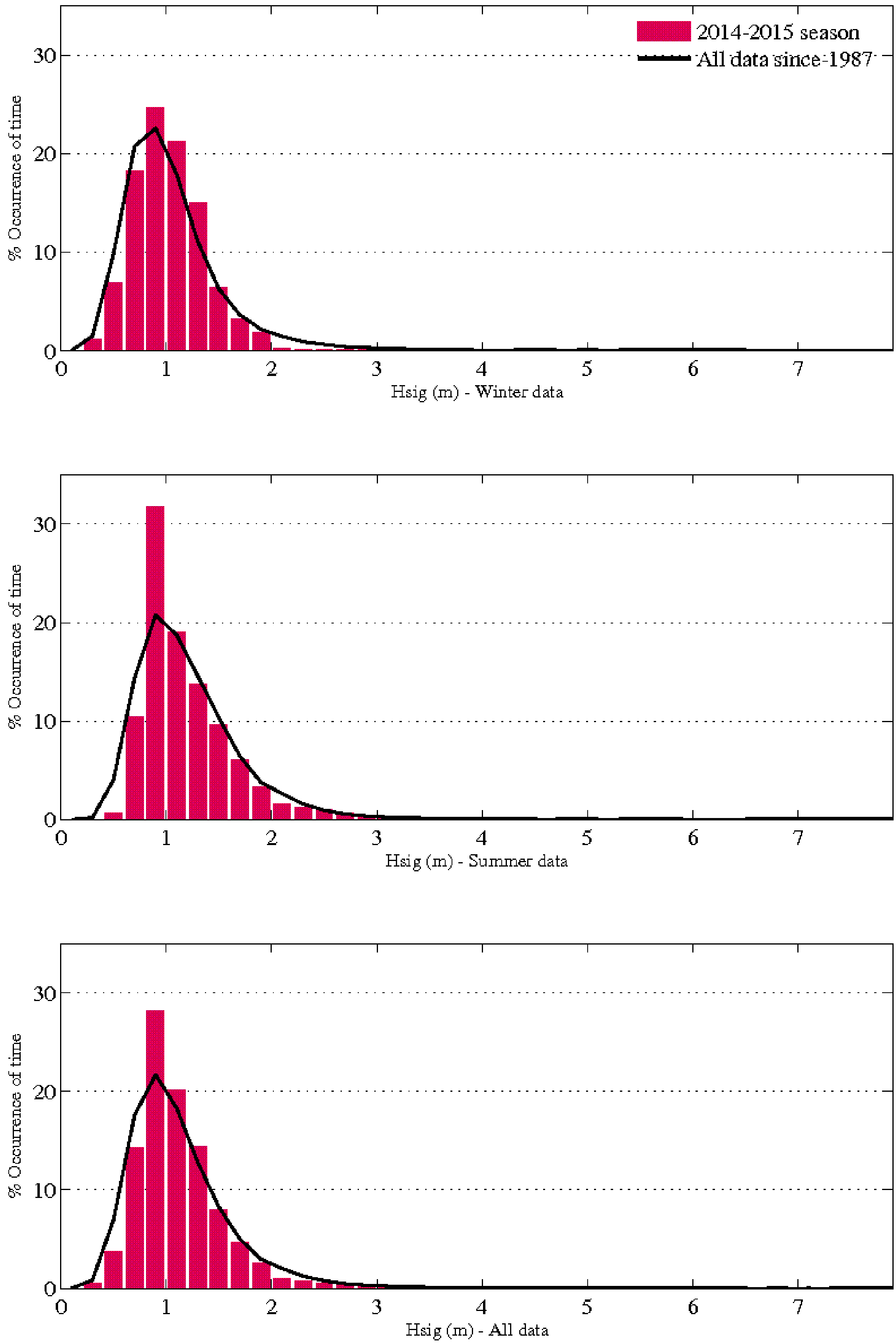


Figure 18 Gold Coast – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

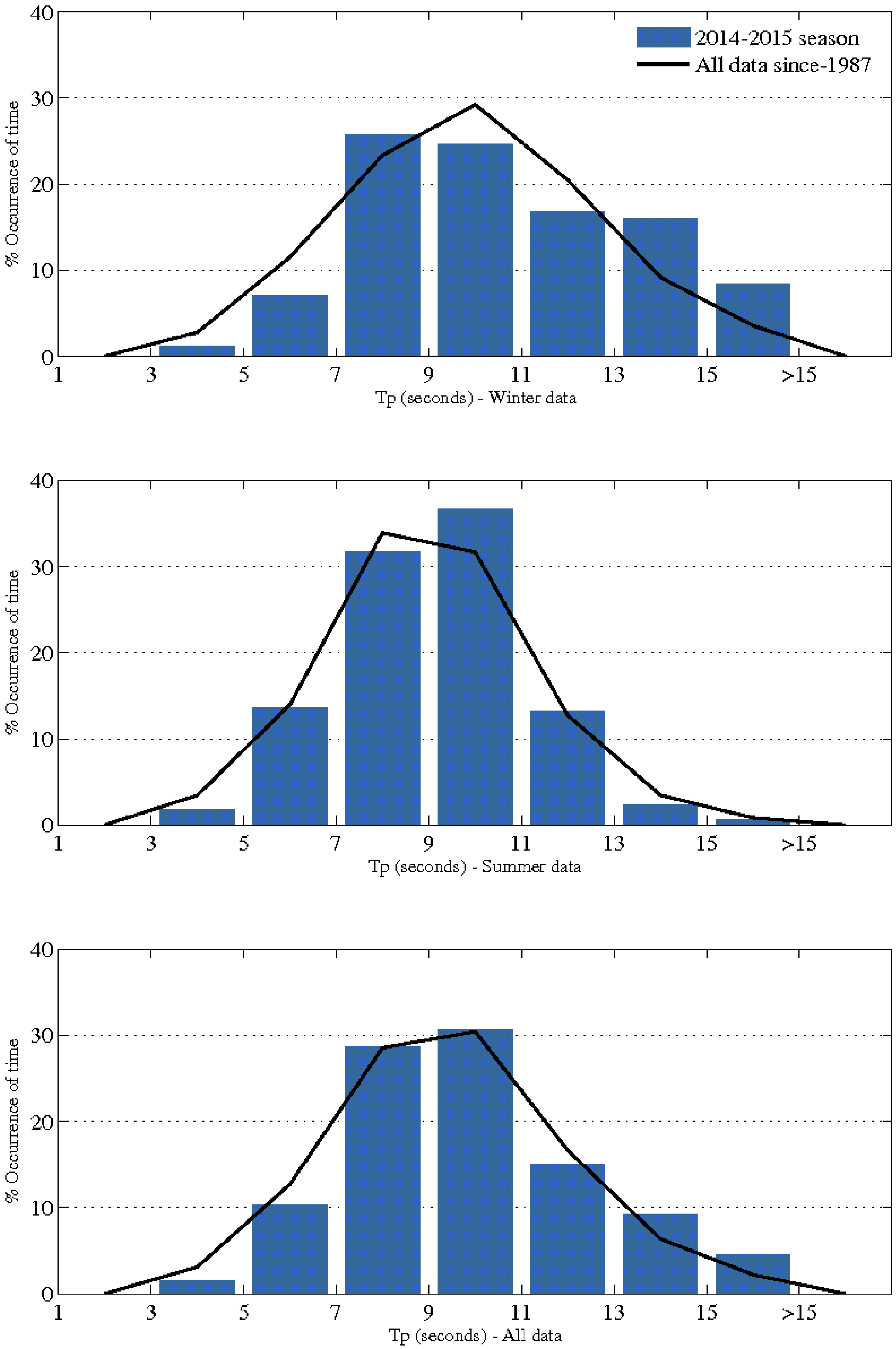


Figure 19 Gold Coast – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

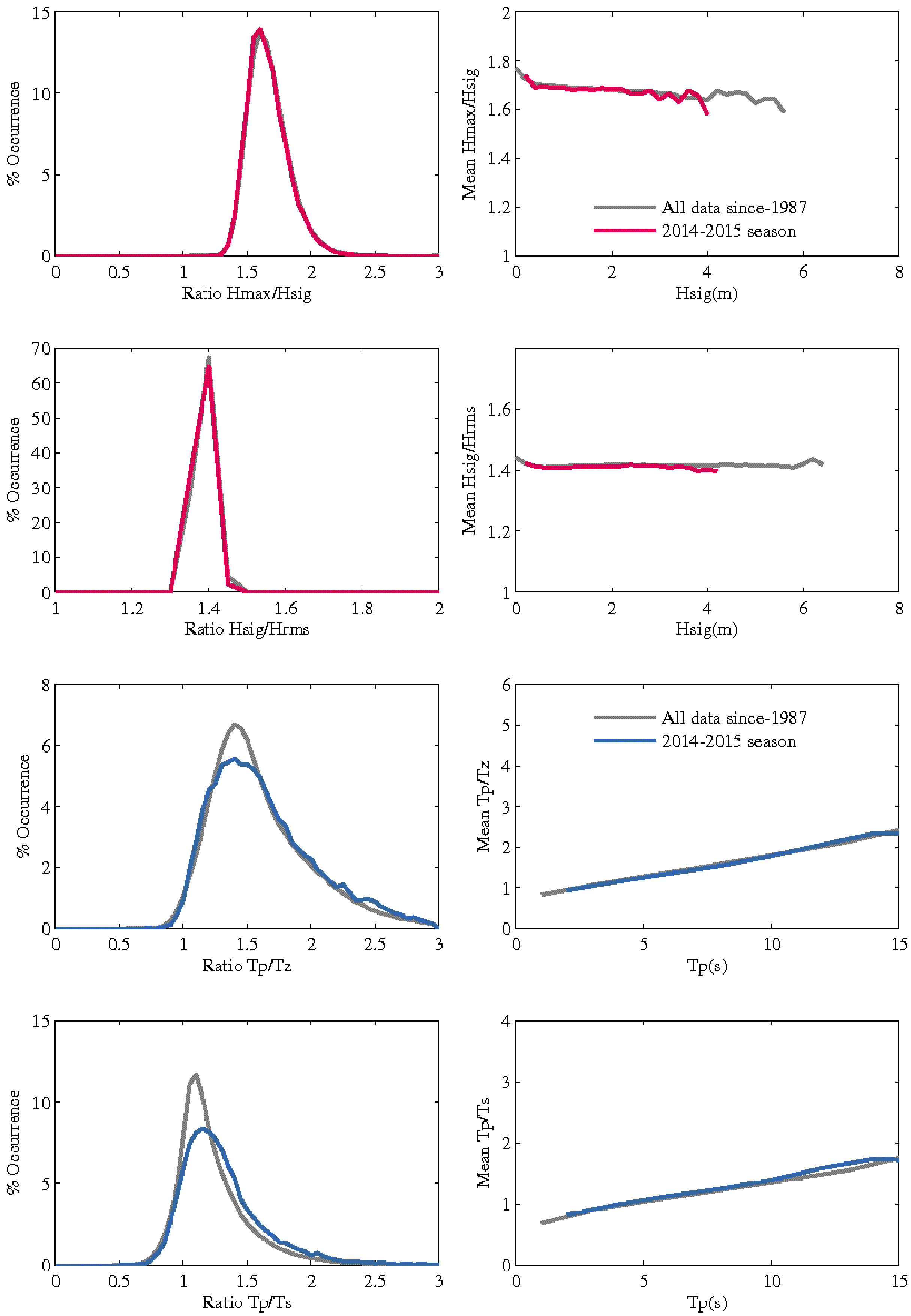
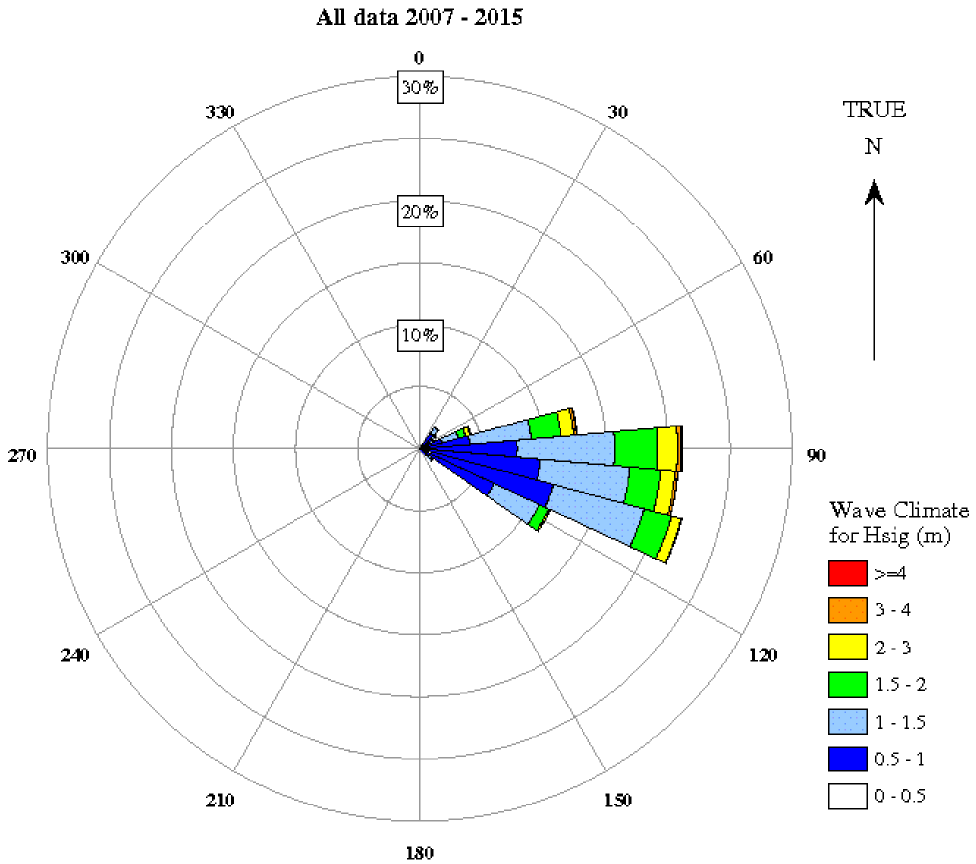


Figure 20 Gold Coast – Wave parameter relationships



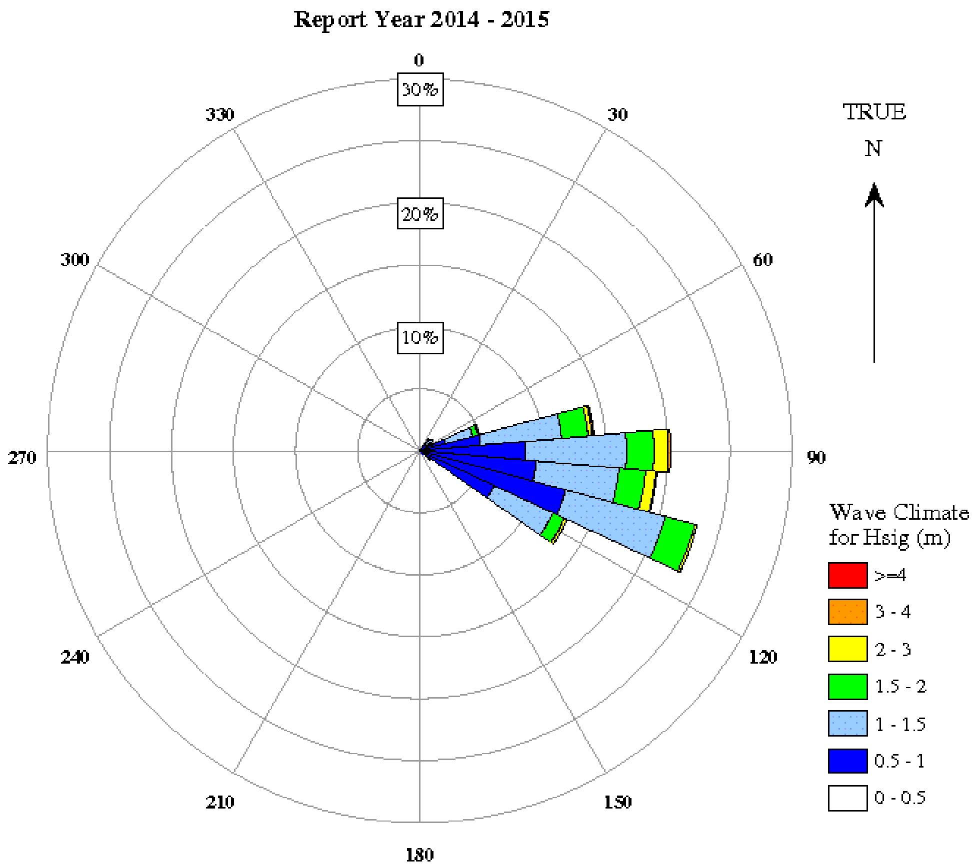


Figure 21 Gold Coast – Directional wave rose

7.3 Brisbane

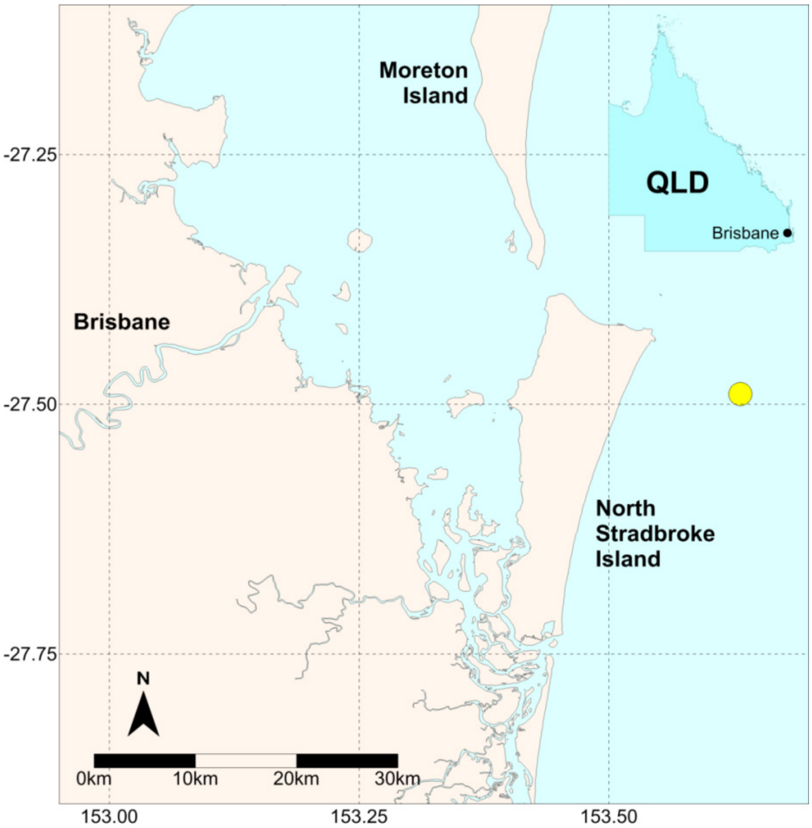


Figure 22 Brisbane – Locality plan

Table 13 Brisbane – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/1976	11.71 years	337,176	39
2014–15	1/11/2014	1.21 days	17,461	1

Table 14 Brisbane – Buoy deployments during the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
27°29.475'S	153°37.955'E	70	31/10/2014	31/03/2015
27°29.600'S	153°37.960'E	70	31/03/2015	current

7.3.1 Brisbane – seasonal overview

The Brisbane wave buoy has been operational for 39 years with an overall data return of 70 per cent. The data recorded for the period November 2014 to October 2015 was very good, with total gaps of 1.21 days, equivalent to a 99.7 percent data return. The buoy was replaced once during the reporting period on 31 March.

There were no recorded wave heights during the reporting period ranking in the highest waves for Brisbane (Table 15). Increases in wave height from the influence TC Ola and TC Marcia (DSITI 2015) during February were captured by the wave buoy (Table 16).The largest waves for the recording period occurred on the 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 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 February, March and September (Figure 25). Average wave heights clearly exceeded +1 sd in February and is likely due to the 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 ranging in the middle of the distribution, 1.0 to 1.6 m, for the summer of the recent period compared to the record. Overall, the wave height distribution was similar between the reporting period and entire record, with a slightly right skew. Histograms of the occurrence of peak wave periods (Tp) (Figure 28) show a similar distribution between the reporting period and record, with a broader spread of Tp during winter. Tp most frequently ranged 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 (Figure 29). The ratio of Tp/Ts shows a lower kurtosis for the recent period compared to the entire record.

Time series for wave direction (Figure 24) shows a broad spread of wave directions from north to south. The directional wave rose plots (Figure 30) more clearly show incident wave directions more frequently from the south-east but with still 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
3/02/2015 23:30	4.1 (4.4)	6.6 (7.4)	9.7	Tropical Cyclone Ola passed into the Coral Sea.
22/02/2015 23:30	4.2 (4.5)	7.2 (8.5)	10.2	TC Marcia formed on 18 February off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate into a low off the southeast Queensland coast.
1/05/2015 20:00	5.3 (5.8)	9.1 (10.8)	11.4	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast Queensland
23/09/2015 20:00	5.2 (5.7)	8.7 (10.7)	11.7	A cold front passed over southern Australia and remained as an east coast low off NSW for several days.

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.

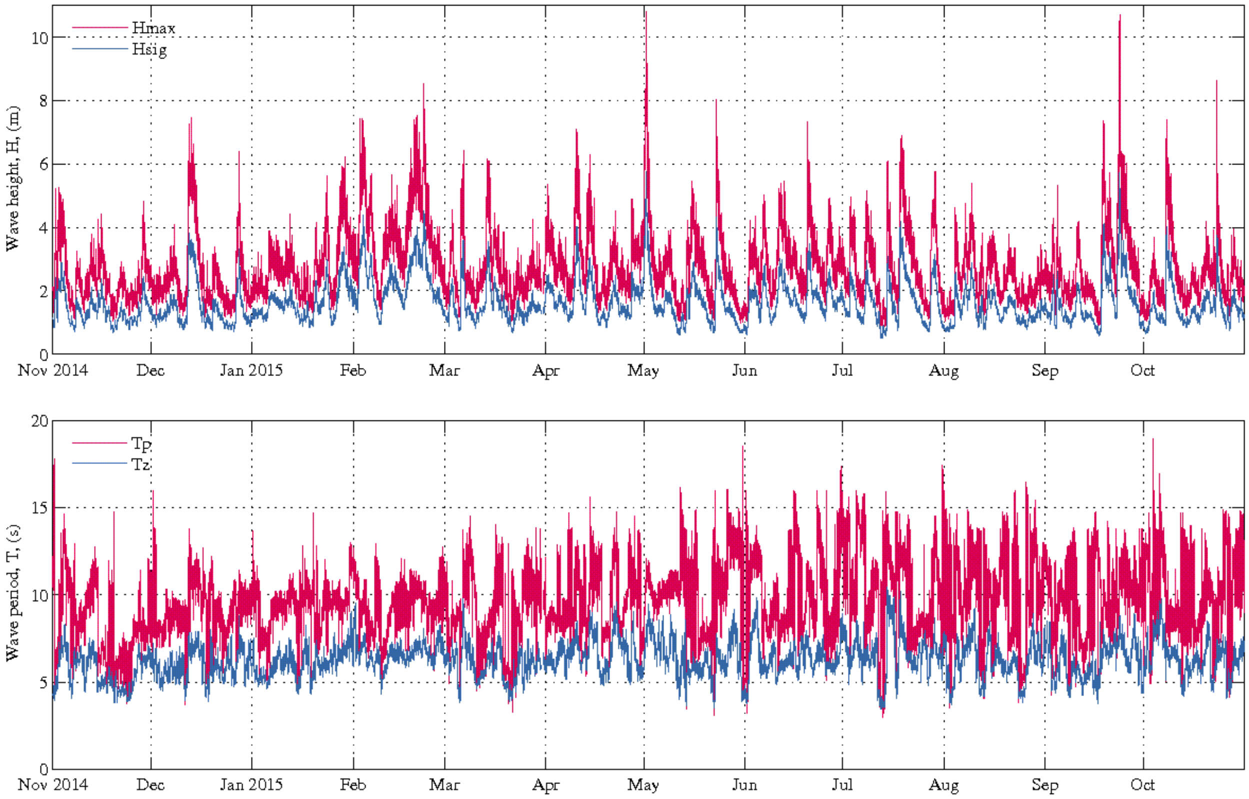


Figure 23 Brisbane – Daily wave recordings

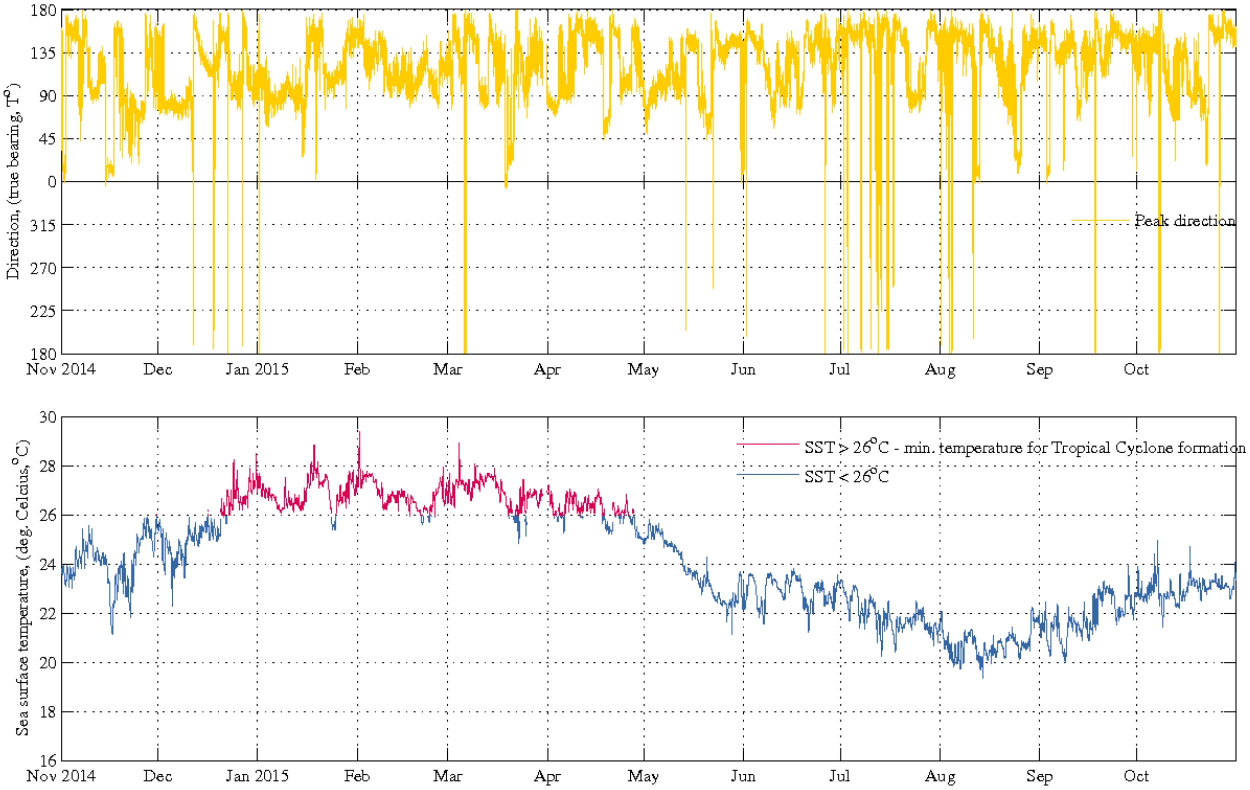


Figure 24 Brisbane – Sea surface temperature and peak wave directions

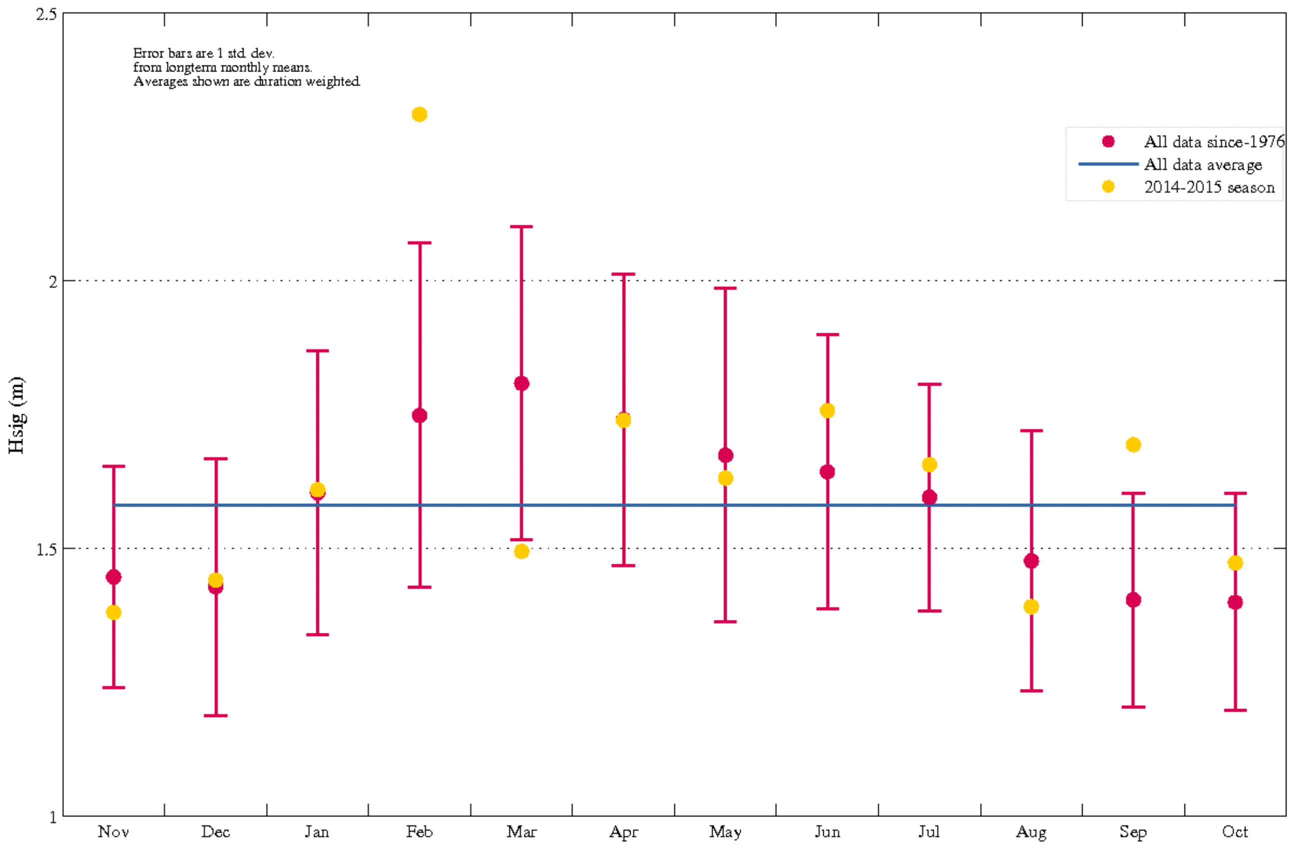


Figure 25 Brisbane – Monthly average wave height (Hsig) for seasonal year and for all data

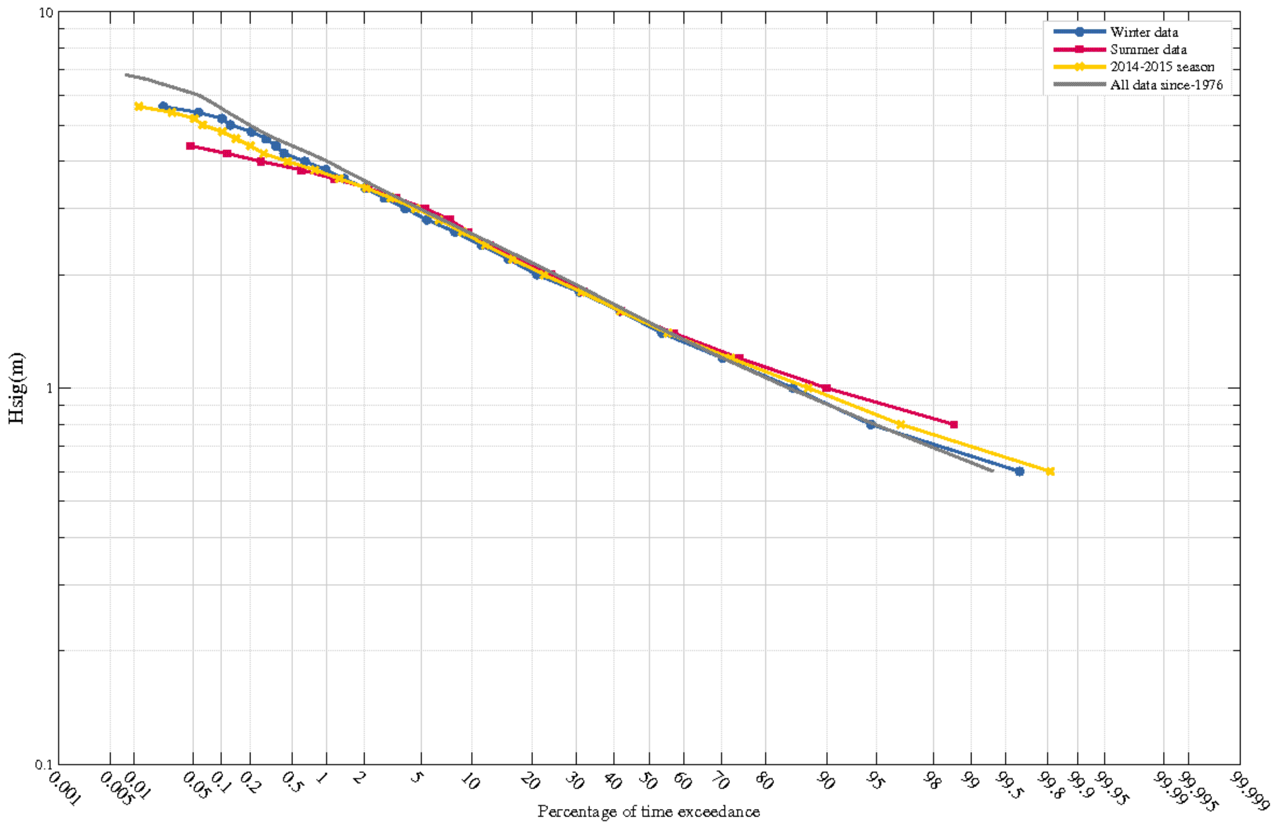


Figure 26 Brisbane – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

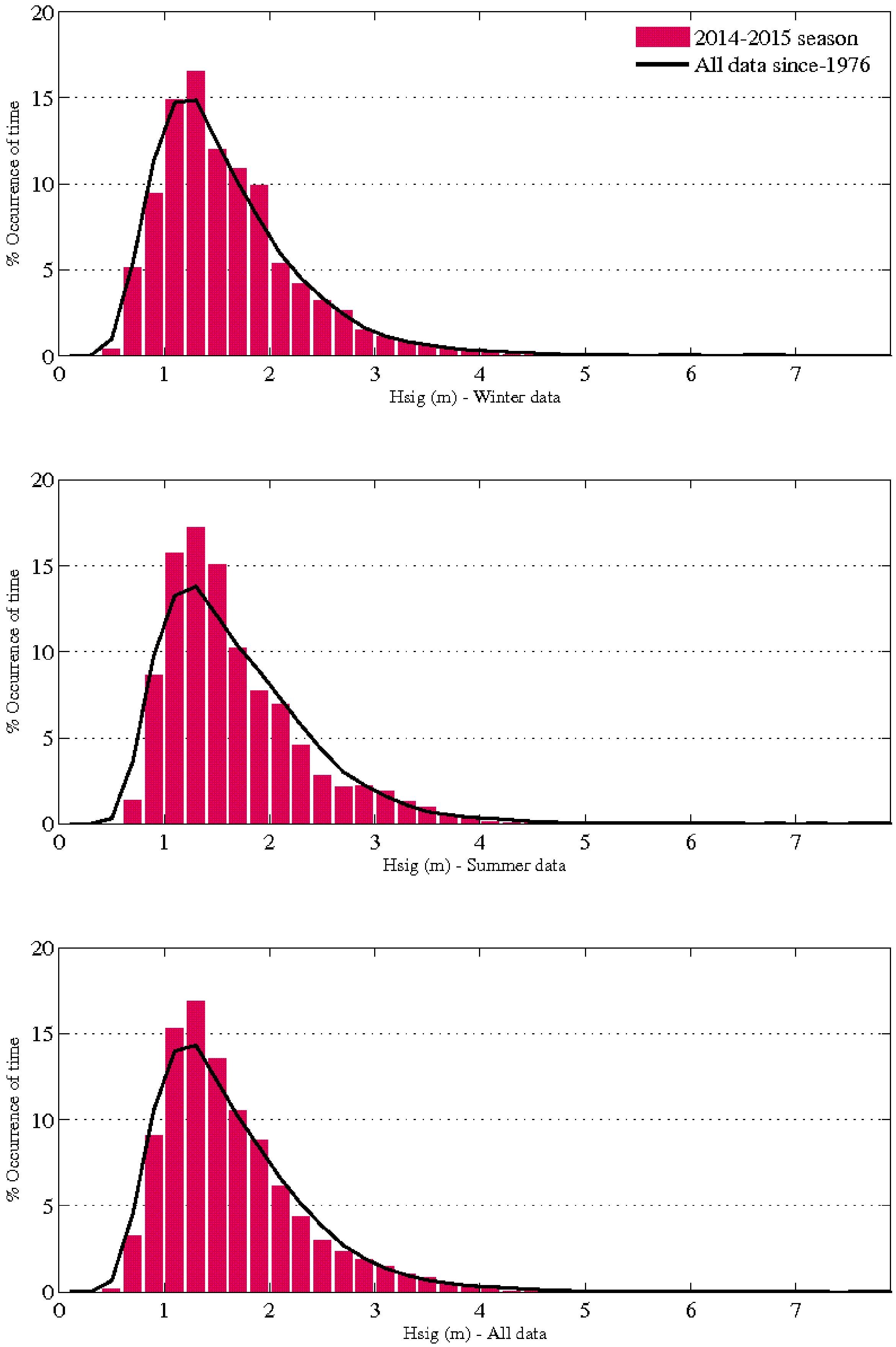


Figure 27 Brisbane – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

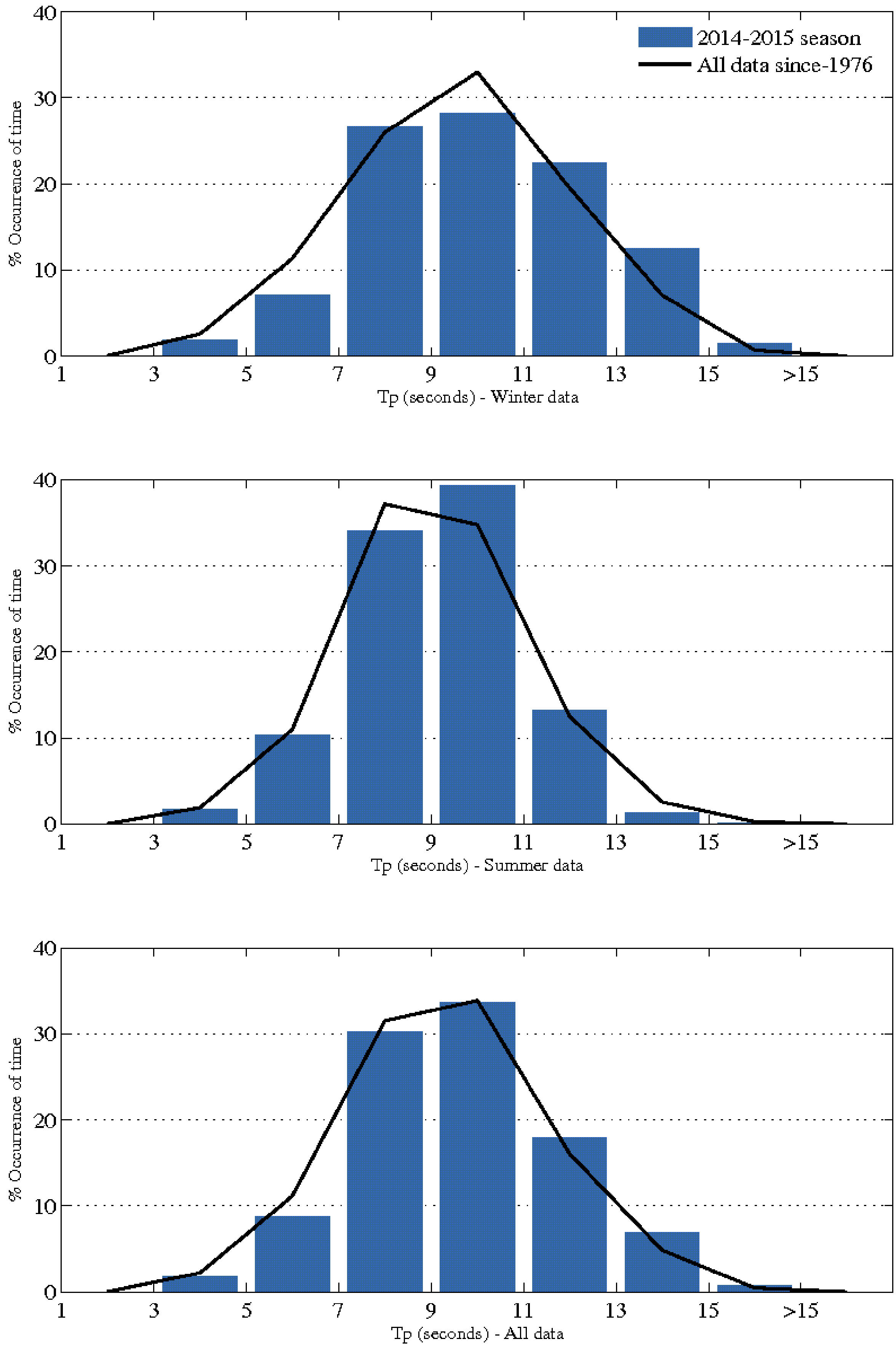


Figure 28 Brisbane – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

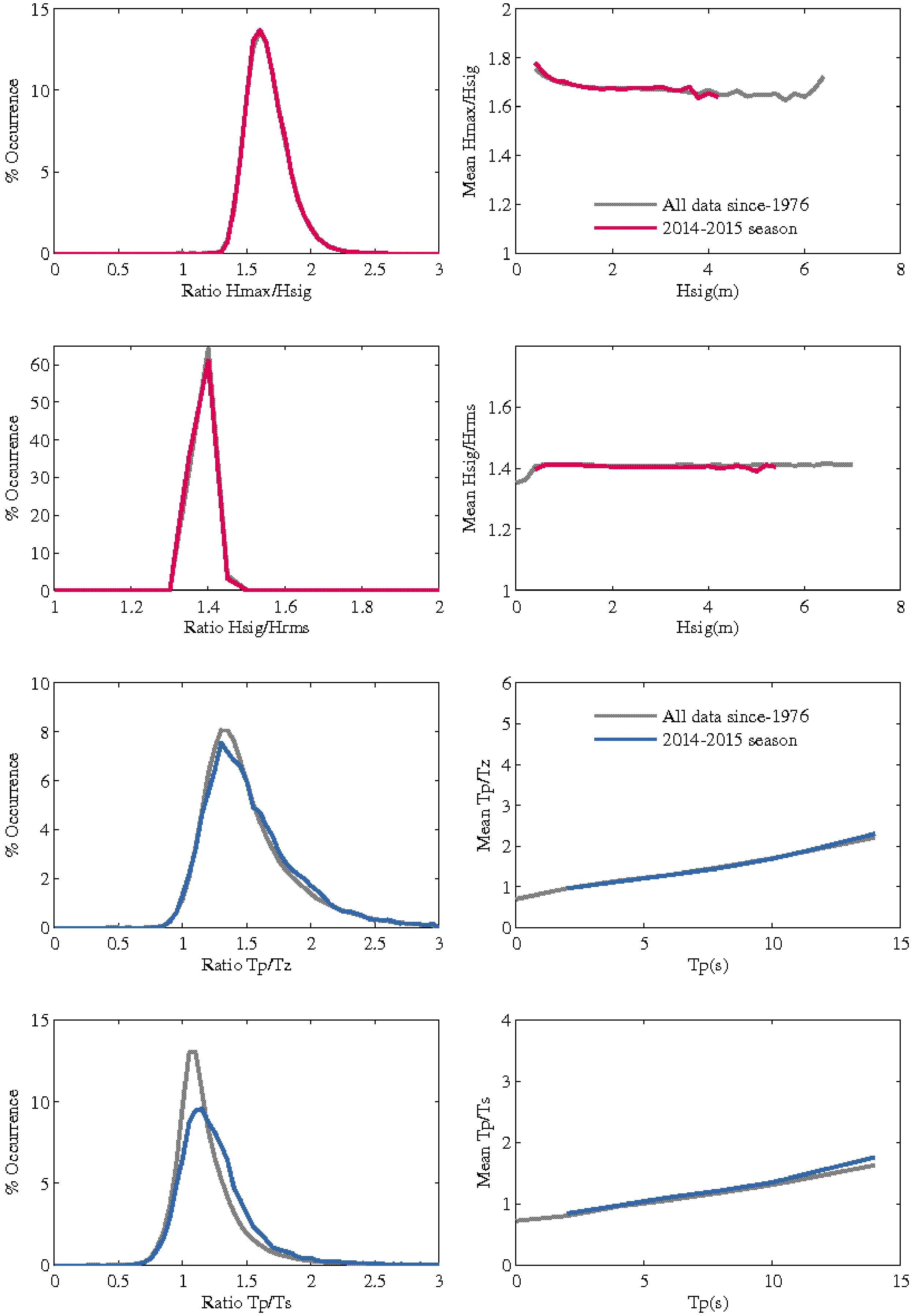
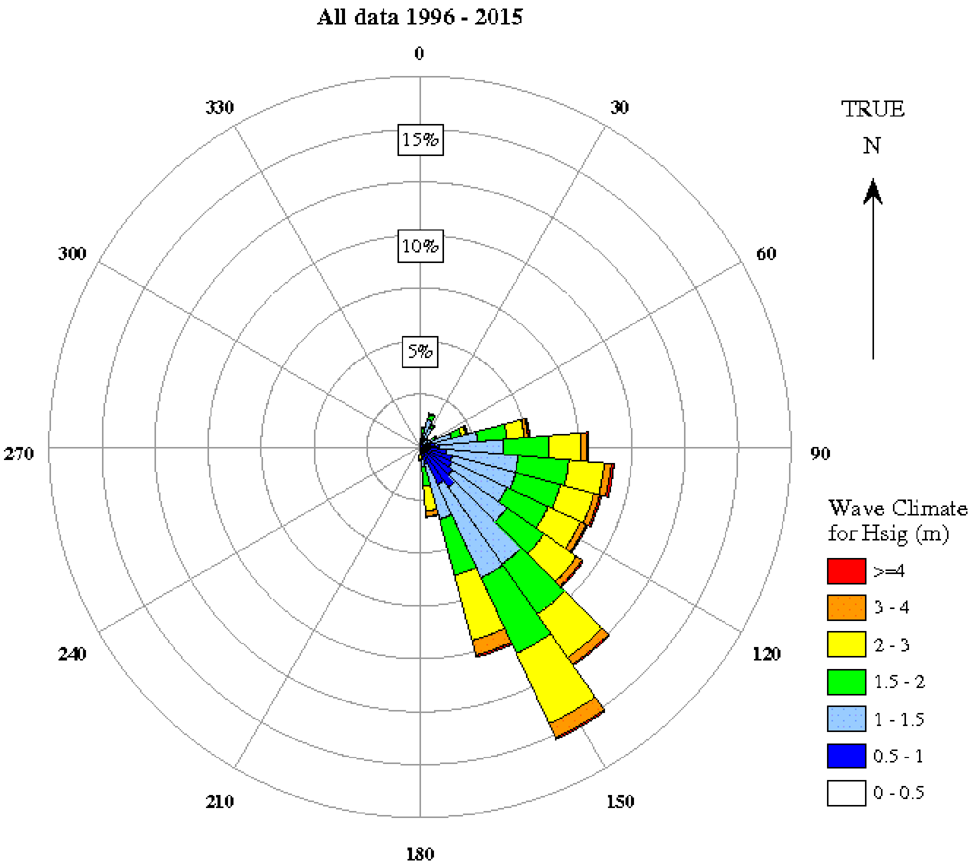


Figure 29 Brisbane – Wave parameter relationships



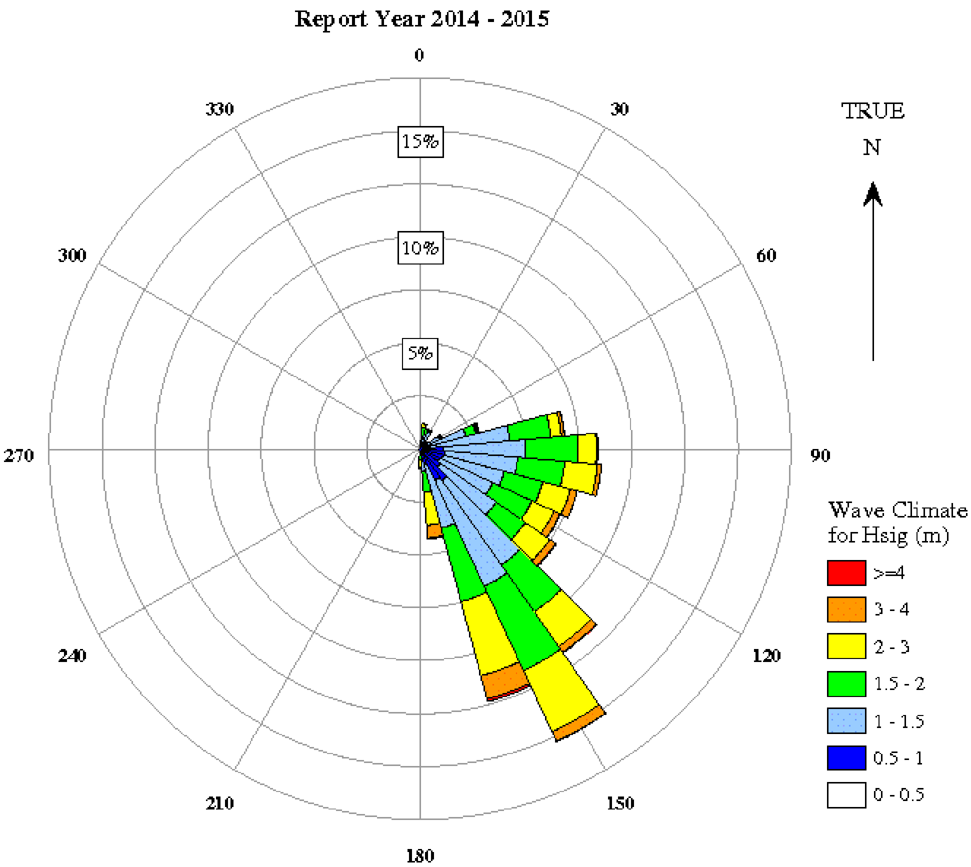


Figure 30 Brisbane – Directional wave rose

7.4 North Moreton

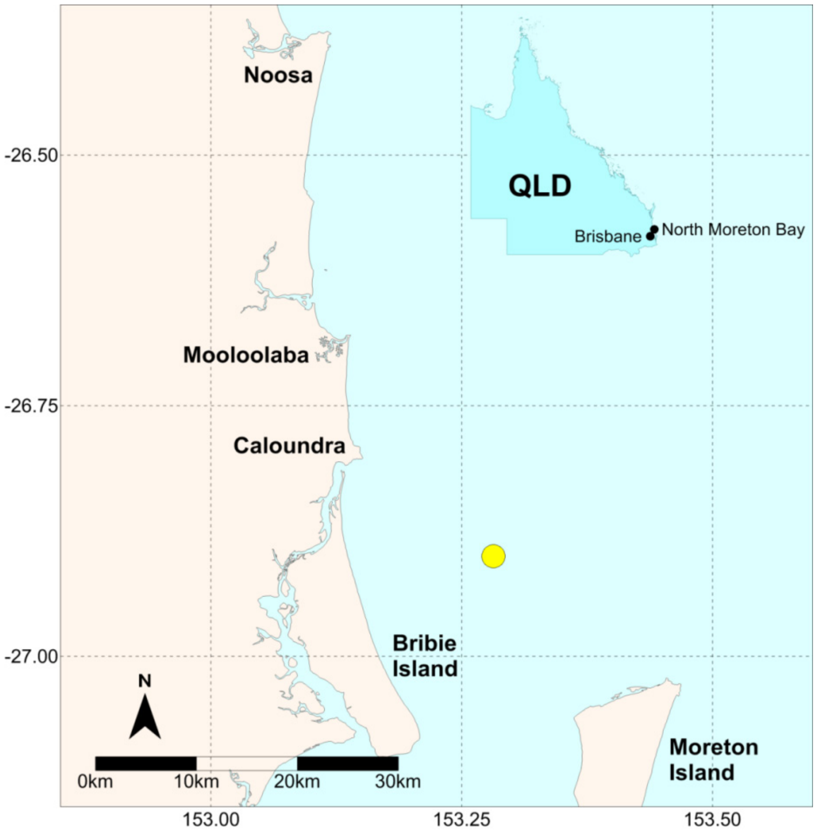


Figure 31 North Moreton – Locality plan

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	90,589	5.24
2014 -15	1/11/2014	4.0 days	17,327	1

Table 18 North Moreton – Buoy deployments during the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°54.910' S	153°16.730' E	35	14/06/2014	22/12/2014
26°53.848' S	153°16.751' E	35	22/12/2014	current

7.4.1 North Moreton – seasonal overview

The North Moreton wave buoy has been operational for over five years with an overall data return of 98.9 per cent. The data record for the period November 2014 to October 2015 was good, with total gaps of four days, equivalent to a 98.1 percent data return. The buoy was replaced once during the reporting period on 22 December 2014 (Table 18).

The North Moreton wave buoy was influenced by waves generated by TC Ola and TC Marcia during February. Waves recorded on 19 February from TC Marcia ranked eighth for highest waves recorded at the site (Table 19), with a significant wave height (Hsig) of 3 m and maximum wave height (Hmax) of 6.2 metres. The largest waves for the reporting period occurred on 01 May from an East Coast Low which developed North of Fraser Island, of 4.9 m Hsig and 9.6 m Hmax, ranking as the second highest waves recorded for North Moreton.

The temperature (sea surface temperature, SST) (Figure33) measured in the buoy hull ranged from 18.5 °C to 28.5 °C. The SST from the end of December to early April was consistently warm enough for tropical cyclone development.

Except for February, March and May, the monthly average Hsig (Figure 34) for the recording period fell within one standard deviation (sd) of the entire record. Positive exceedance for average Hsig in February and May is due to the influence of the two cyclones and the East Coast Low during those months.

The wave climate during the reporting period was very similar to the wave climate of the whole record, as seen in the percentage exceedance plot (Figure 35). Histograms for occurrence of Hsig (Figure 36) show a slightly higher right skew for winter and a greater occurrence of the modal 0.8 to 1.0 Hsig waves in summer for the reporting period compared to the record. Histograms of the occurrence of peak wave periods (Tp) (Figure 37) show a much greater occurrence of the modal 7 to 9 second Tp and a subsequent decrease in the occurrence of the remaining distribution during summer for the reporting period compared to the 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 38.

The time series for wave direction (Figure 33) shows a peak wave direction generally from the east to southeast, with swings to the north throughout winter 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	25/12/2011 07:00	3.9	25/12/2011 07:00	7.3

4	19/02/2013 11:30	3.5	19/02/2013 15:30	6.3
5	28/06/2012 02:30	3.2	19/02/2015 11:00	6.2
6	17/01/2012 06:30	3	28/06/2012 05:30	5.7
7	12/10/2010 13:30	3	22/08/2011 08:30	5.7
8	19/02/2015 12:30	3	27/03/2014 22:30	5.7
9	12/06/2012 15:30	2.9	16/01/2011 22:00	5.7
10	11/08/2010 02:00	2.9	17/01/2012 06:30	5.6

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
03/02/2015 12:30	2.2 (2.4)	3.6 (4.5)	9.1	Tropical Cyclone Ola passed into the Coral Sea.
19/02/2015 12:30	2.8 (3.0)	5.1 (6.2)	10.0	TC Marcia formed on 18 February off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate into a low off the southeast Queensland coast.
01/05/2015 15:30	4.4 (4.9)	7.3 (9.6)	11.4	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast 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.

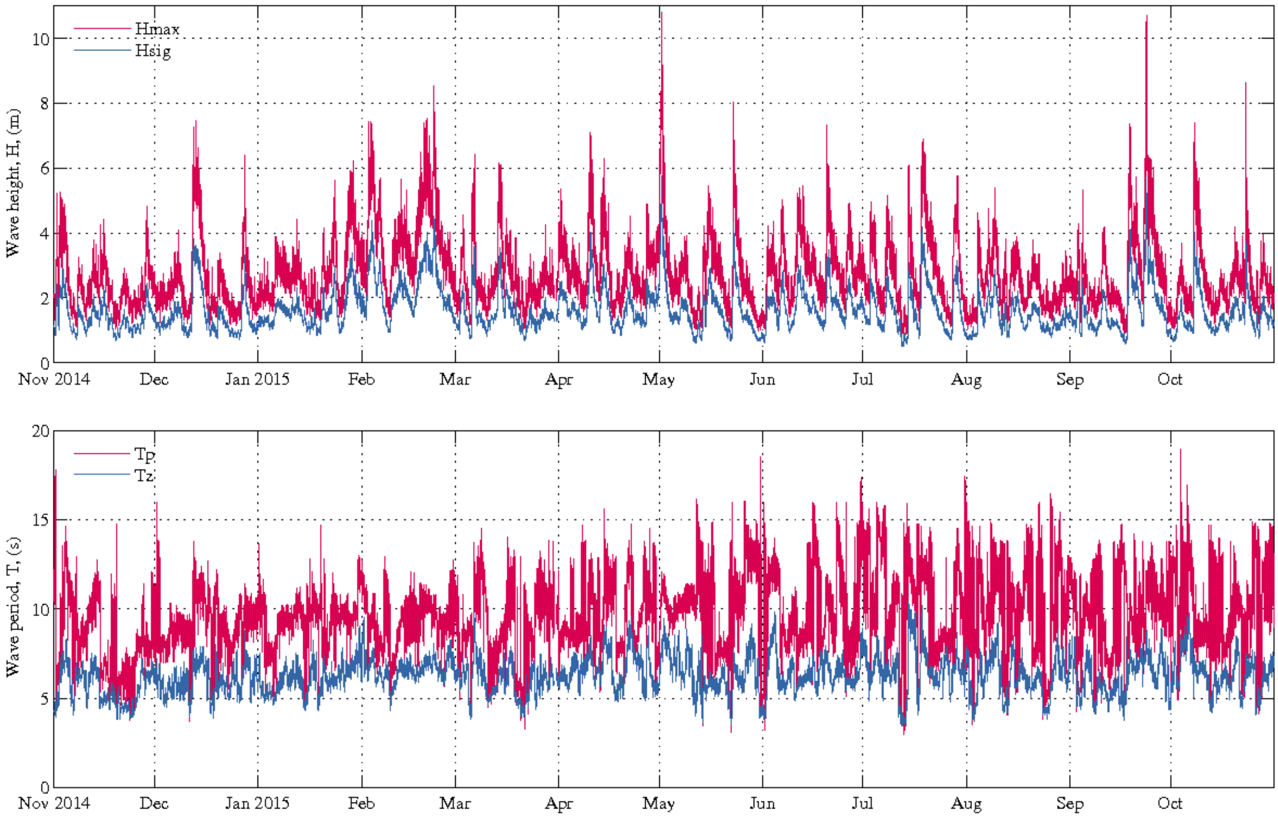


Figure 32 North Moreton – Daily wave recordings

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

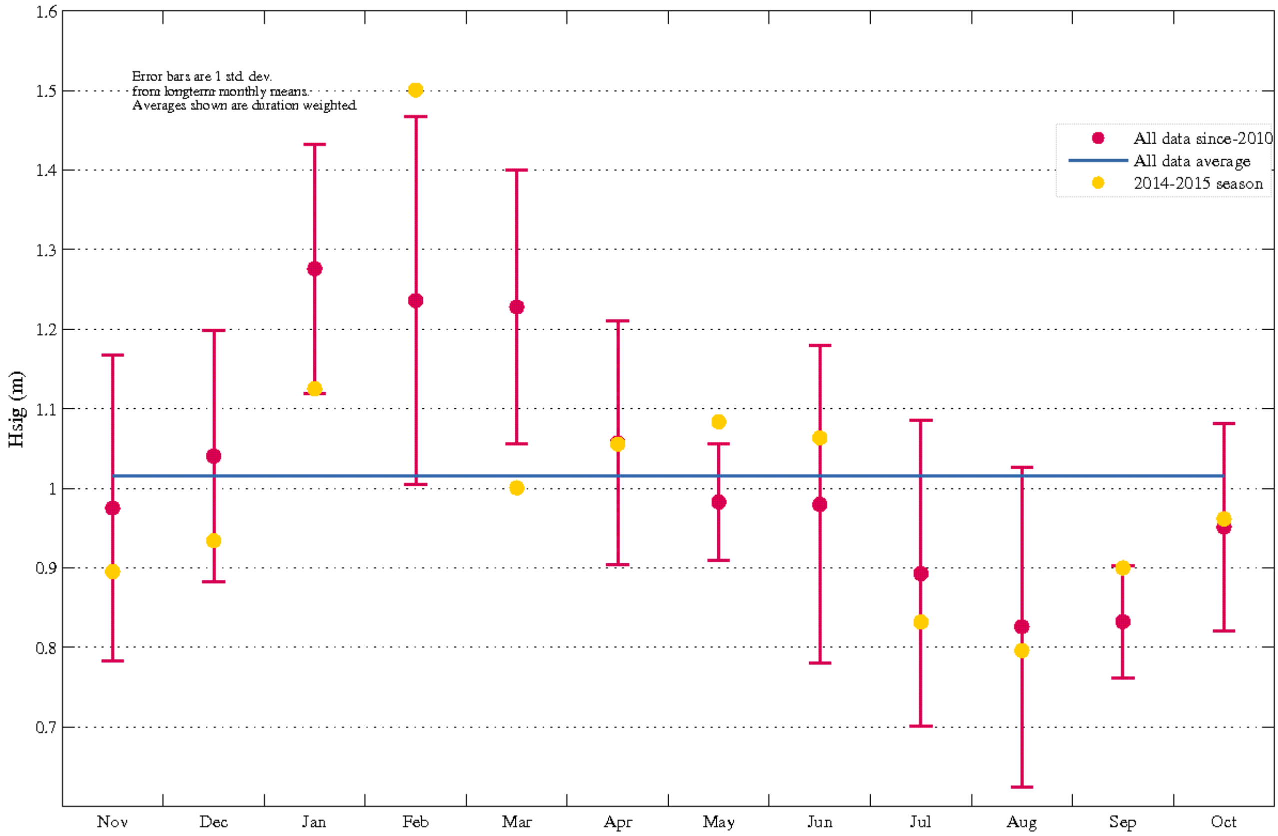


Figure 34 North Moreton – Monthly average wave height (Hsig) for seasonal year and for all data

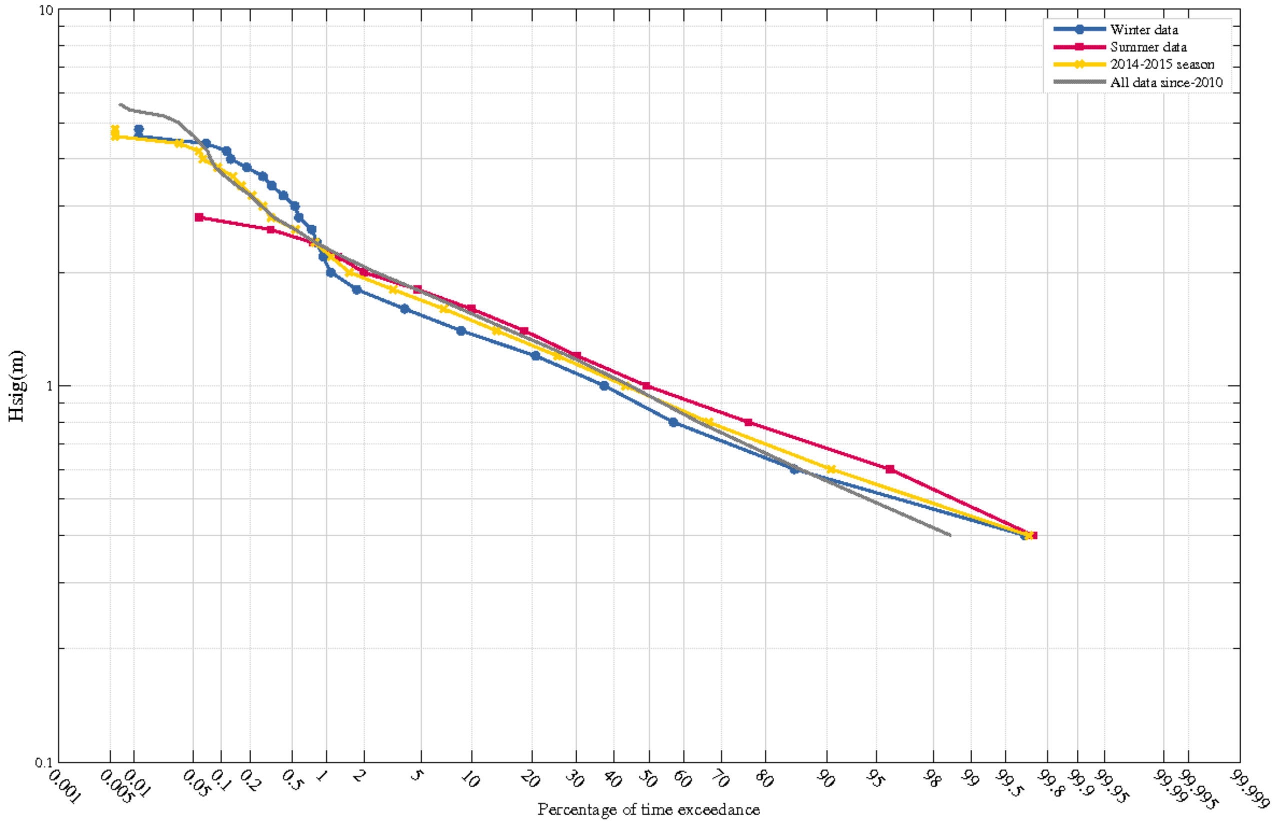


Figure 35 North Moreton – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

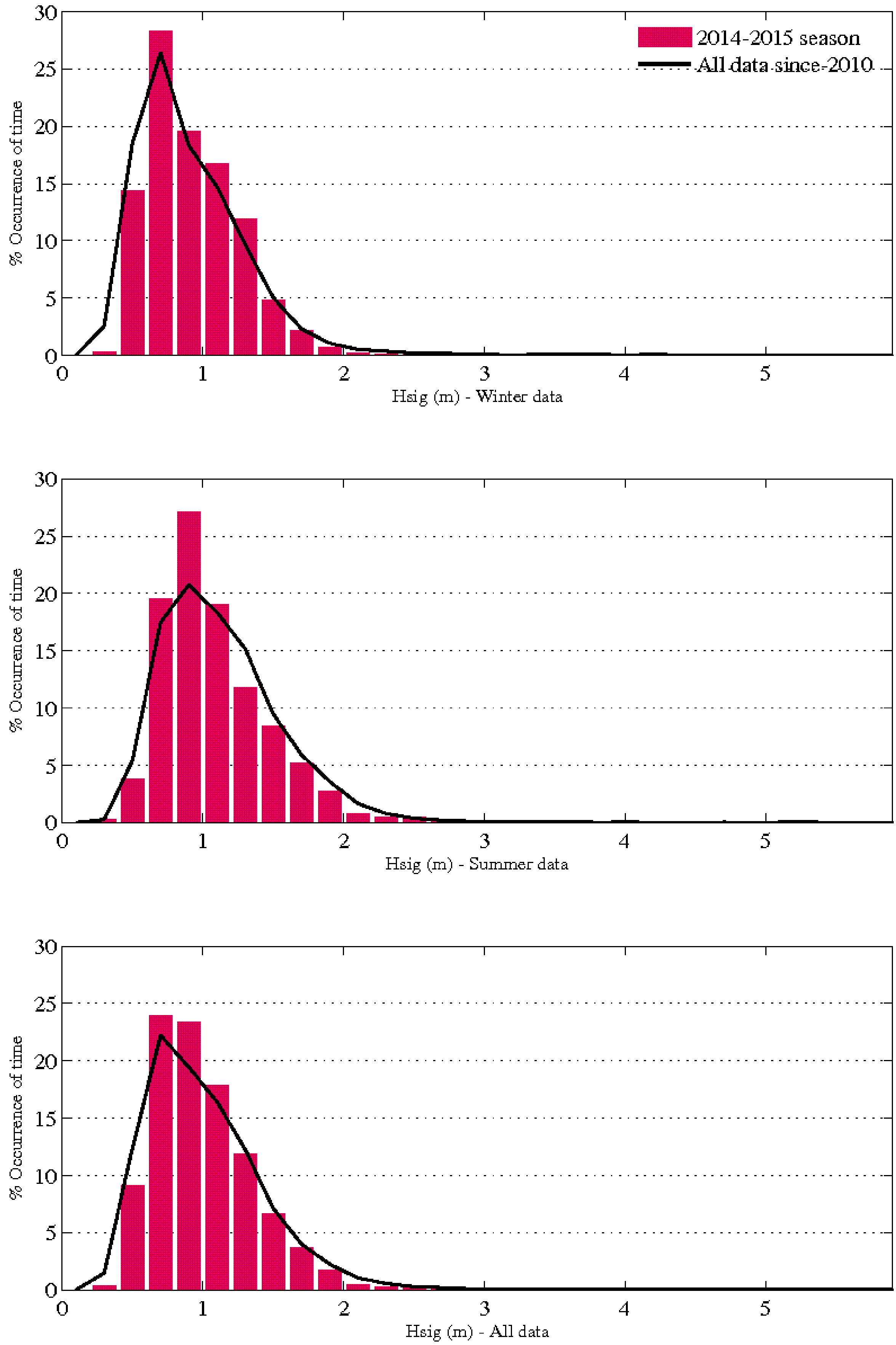


Figure 36 North Moreton – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

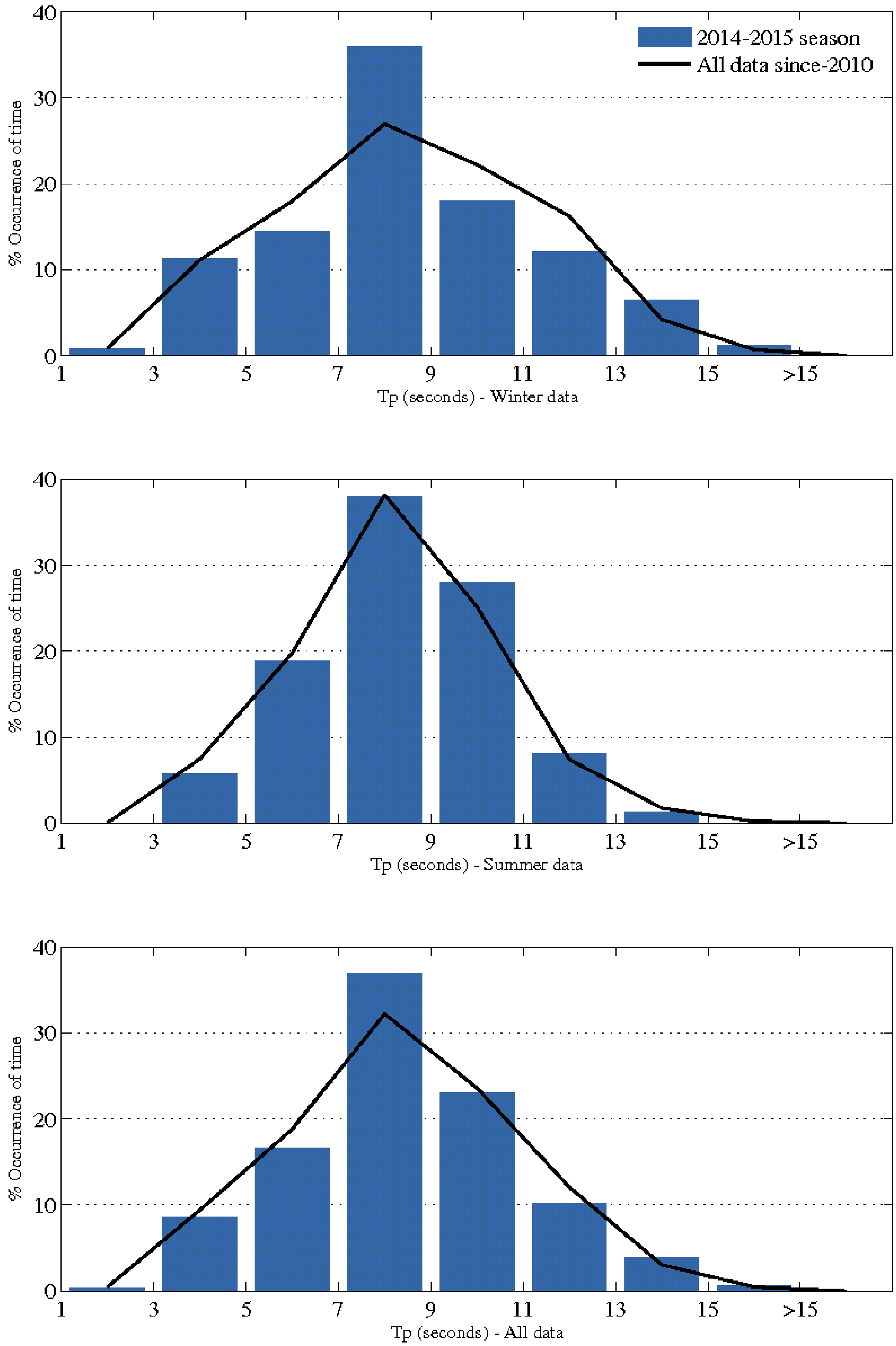


Figure 37 North Moreton – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

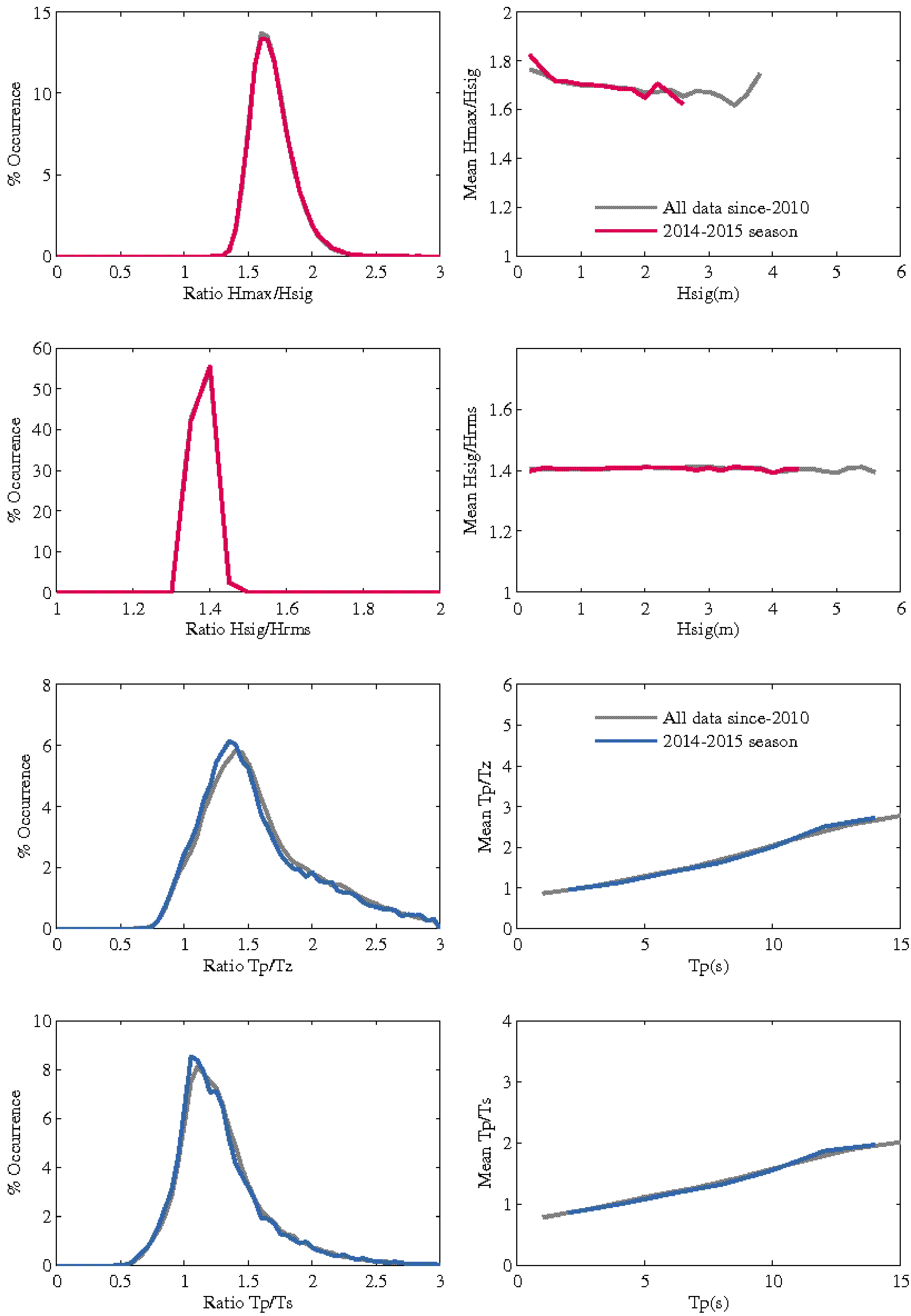
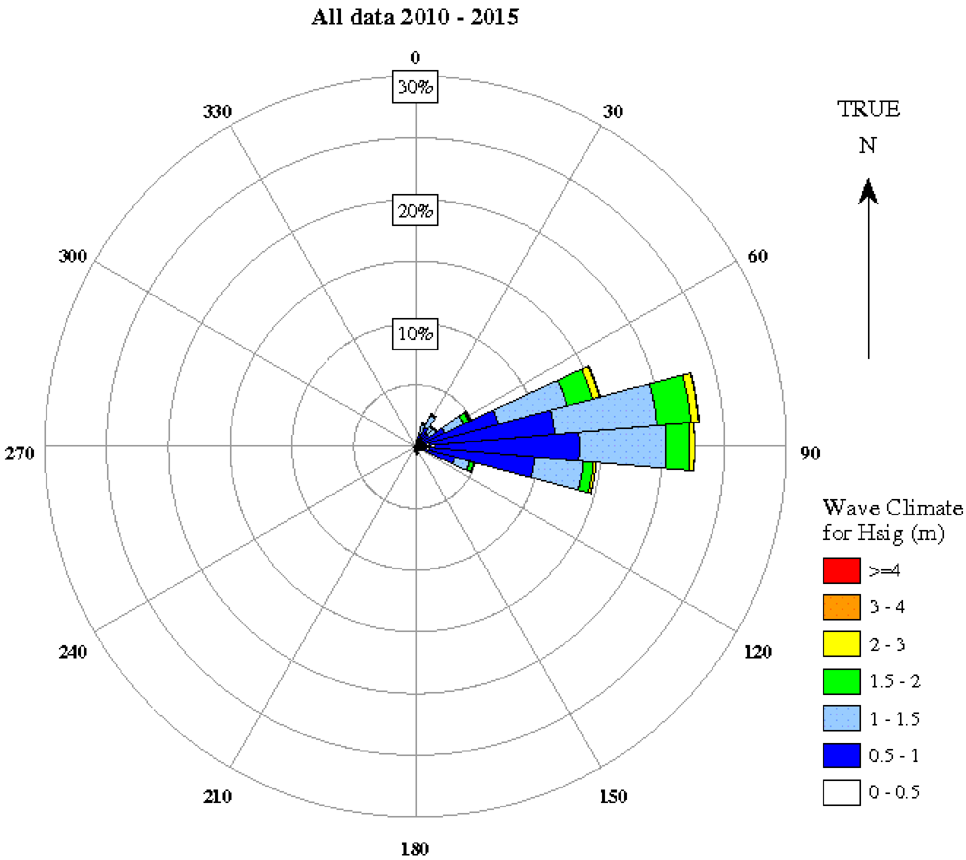


Figure 38 North Moreton – Wave parameter relationships



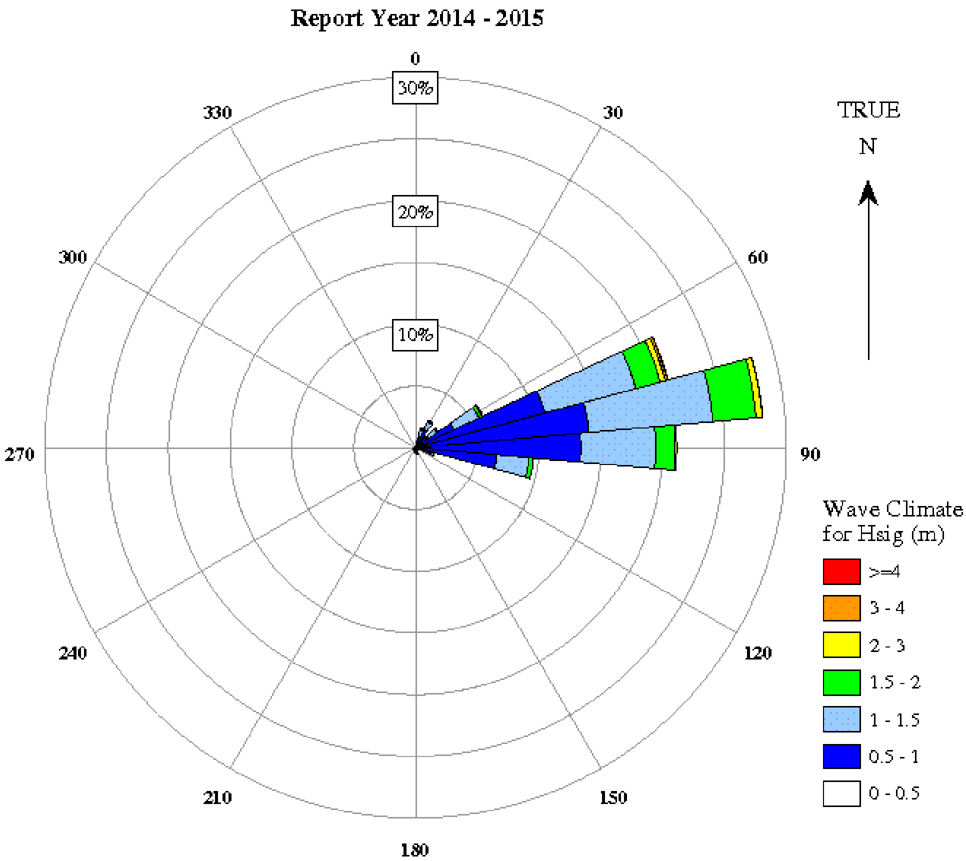


Figure 39 North Moreton – Directional wave rose

7.5 Caloundra

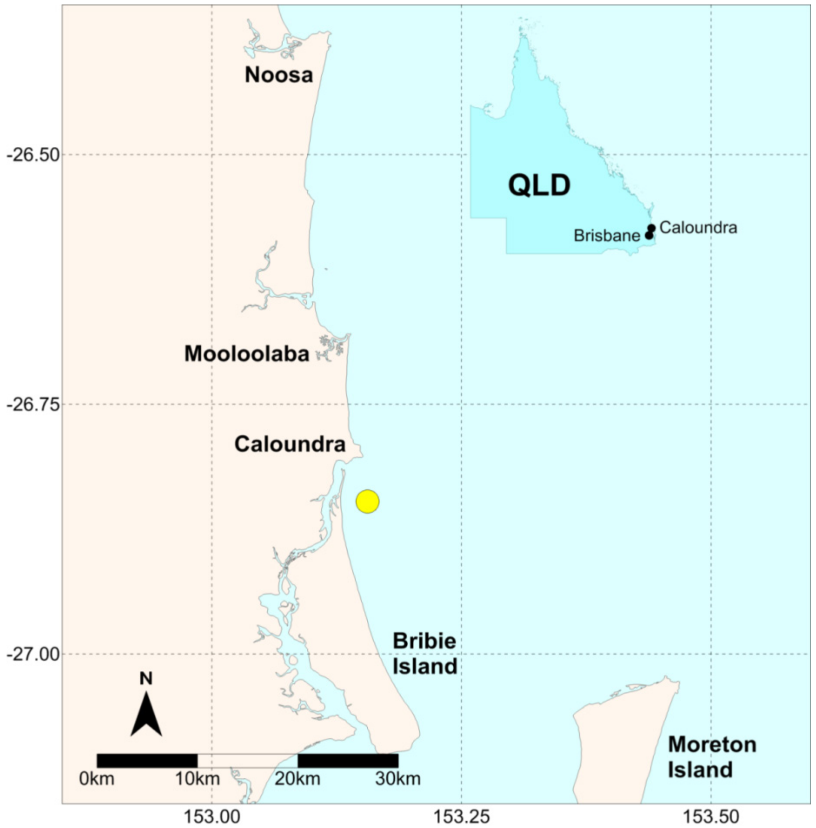


Figure 40 Caloundra – Locality plan

Table 21 Caloundra – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2013	0.11 years	41,941	2.5
2014–15	01/11/2014	13.92 days	16,851	1

Table 22 Caloundra – Buoy deployments for 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°50.999' S	153°09.000' E	14	02/09/2014	09/07/2015
26°50.855' S	153°09.346' E	16	09/07/2015	current

7.5.1 Caloundra – seasonal overview

The Caloundra wave buoy has only been operational since 01 May 2013 with an overall data return of 96 per cent. The data recorded for the period November 2014 to October 2015 was good, with total gaps of 13.9 days, equivalent to 96.2 per cent data return. The buoy was replaced once during the reporting period on 09 July. Due to the short length of the data set, this report has made no comments or comparisons against any historical data.

The influence to wave heights at Caloundra from TC Marcia and an East Coast Low which developed north of Fraser Island (Table 24) is seen in the time series for wave heights (Figure 41) as prominent peaks in February and May. The largest waves resulted from the East Coast Low on 01 May with a significant wave height (Hsig) of 4.9 m and a maximum wave height (Hmax) of 9.6 m.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 17° C to 29° C (Figure 42). The SST from the end of December to April was warm enough for tropical cyclone development.

Histograms for occurrence of Hsig (Figure 45) show a median height of 0.6–0.8 m during winter and a modal height of 0.8–1.0 m during summer. Histograms for occurrence of peak wave period (Tp) (Figure 46) show a median period of 7 to 9 second throughout the year.

The time series for wave direction (Figure 42) show waves predominantly from the east, swinging at times to northeast. Wave directions from the southwest in July are likely to be erroneous recordings given the proximity of the wave buoy to nearby Bribie Island. Directional wave rose plots (Figure 48) show the dominant 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	19/02/2015 07:30	3.2	19/02/2015 07:30	6.2
3	27/03/2014 21:00	2.6	27/03/2014 22:00	4.8
4	16/03/2014 03:00	2.4	17/08/2014 06:00	4.4
5	17/08/2014 05:30	2.2	29/01/2014 22:30	4.2
6	03/02/2015 12:00	2.2	11/03/2014 12:30	4.2
7	28/01/2014 22:30	2.2	02/07/2013 01:30	4.1
8	11/03/2014 09:30	2.1	03/02/2015 07:00	4.1

9	18/05/2014 01:30	2.1	17/05/2014 23:30	3.8
10	01/04/2015 11:00	2.0	01/04/2015 16:30	3.8

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
19/02/2015 12:30	2.8 (3.0)	5.1 (6.2)	10.0	TC Marcia formed on the 18 February off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate into a low off the southeast Queensland coast.
01/05/2015 15:30	4.4 (4.9)	7.3 (9.6)	11.4	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast 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.

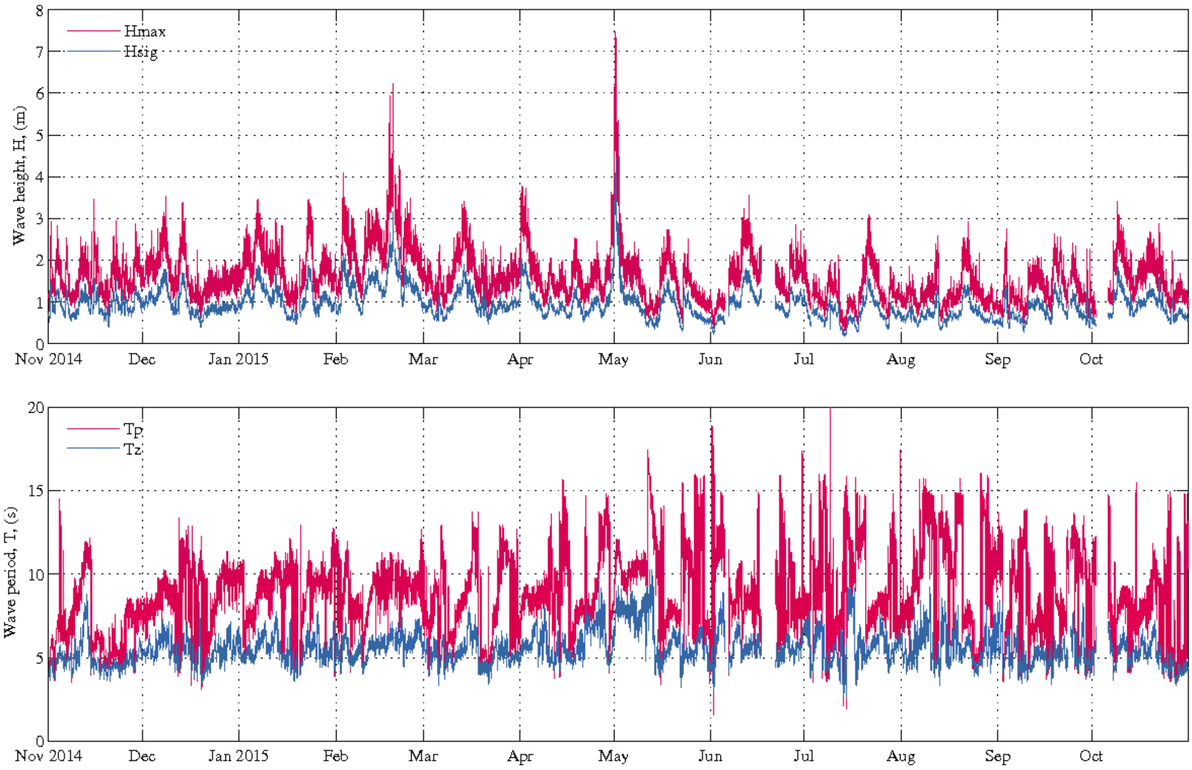


Figure 41 Caloundra – Daily wave recordings

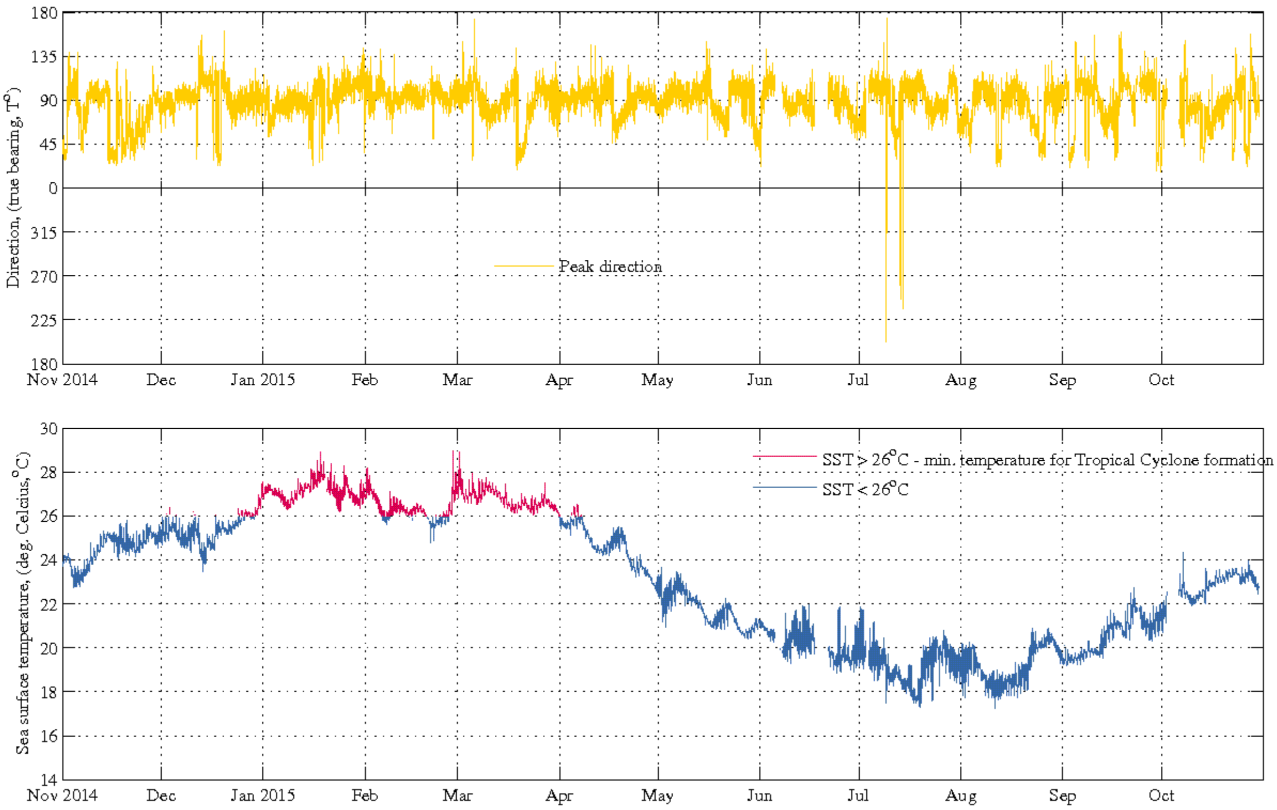


Figure 42 Caloundra – Sea surface temperature and peak wave directions

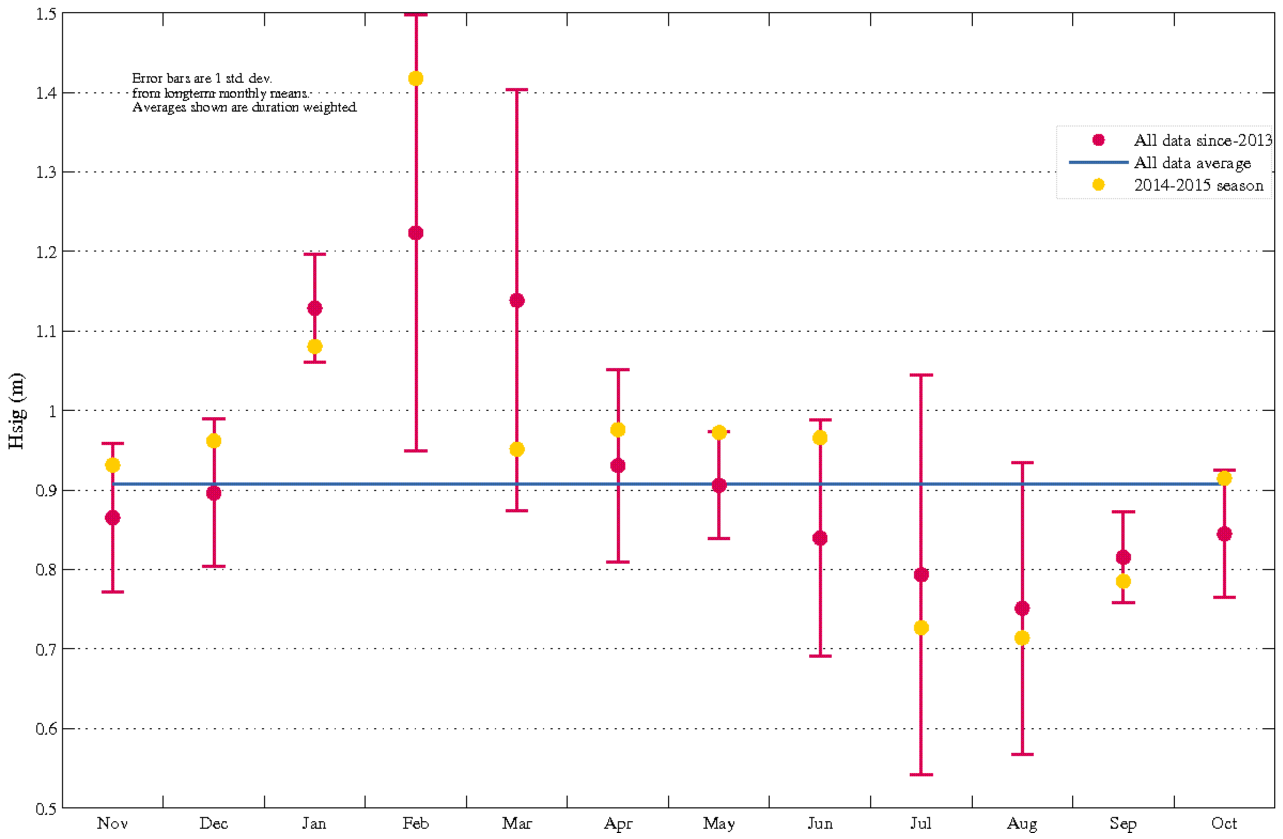


Figure 43 Caloundra – Monthly average wave height (Hsig) for seasonal year and for all data

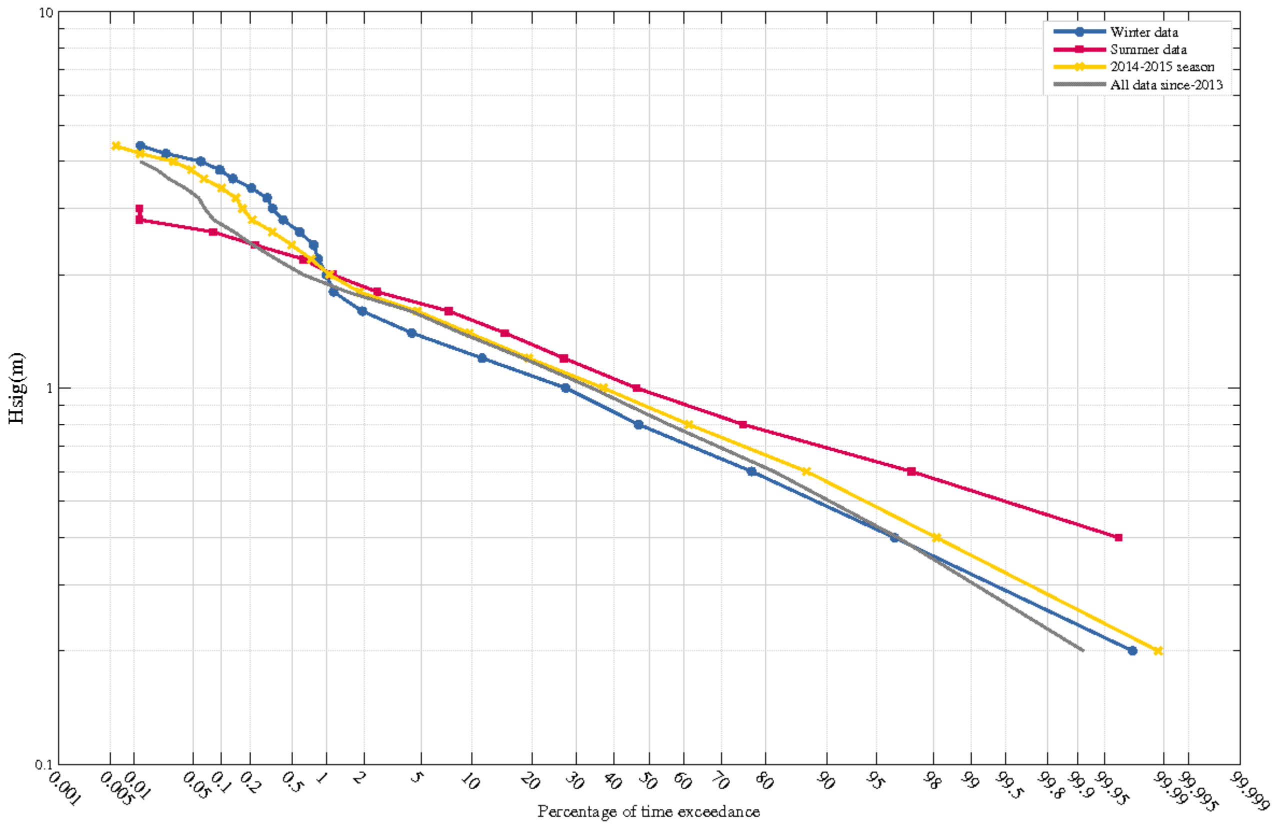


Figure 44 Caloundra – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

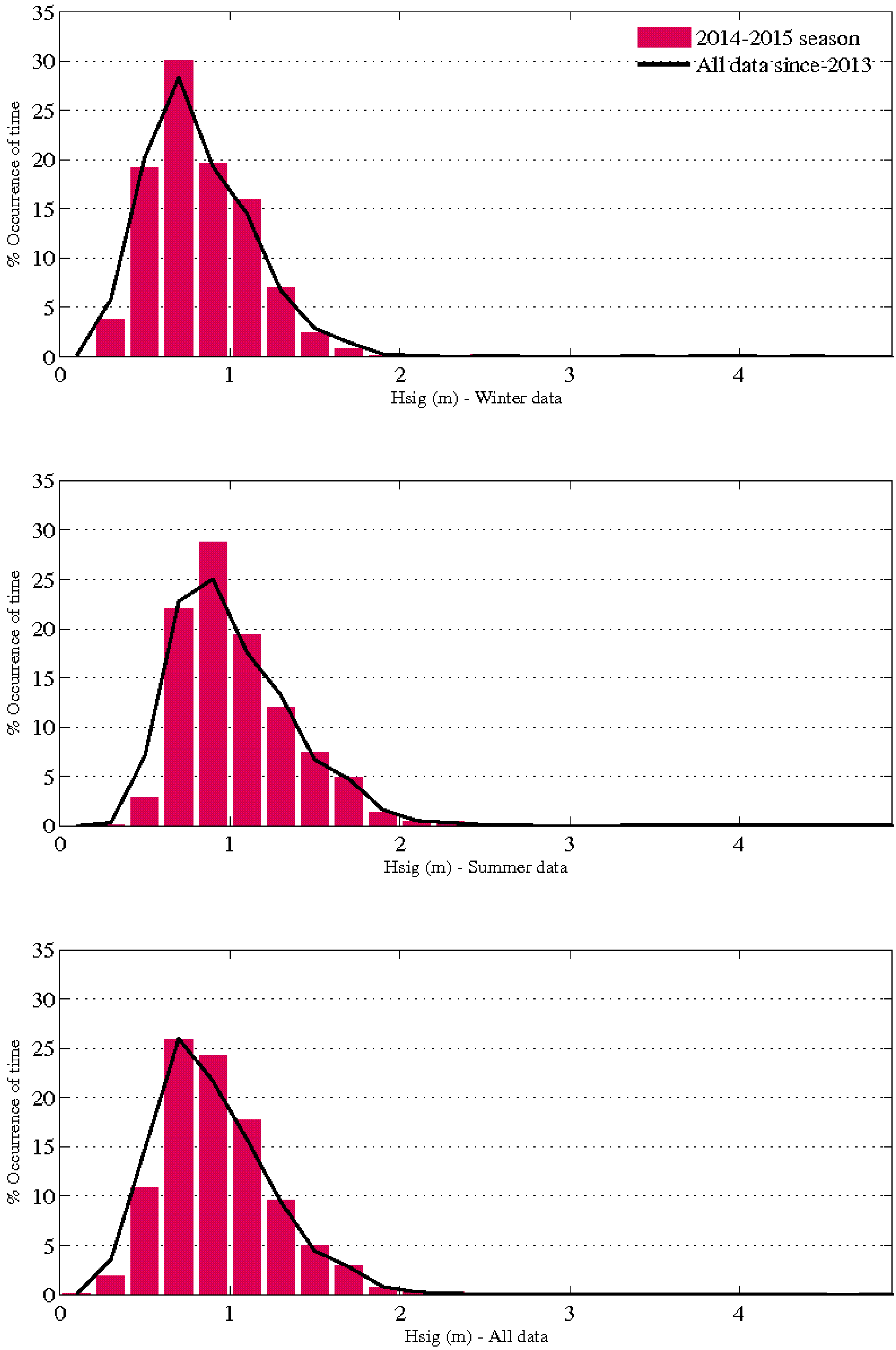


Figure 45 Caloundra – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

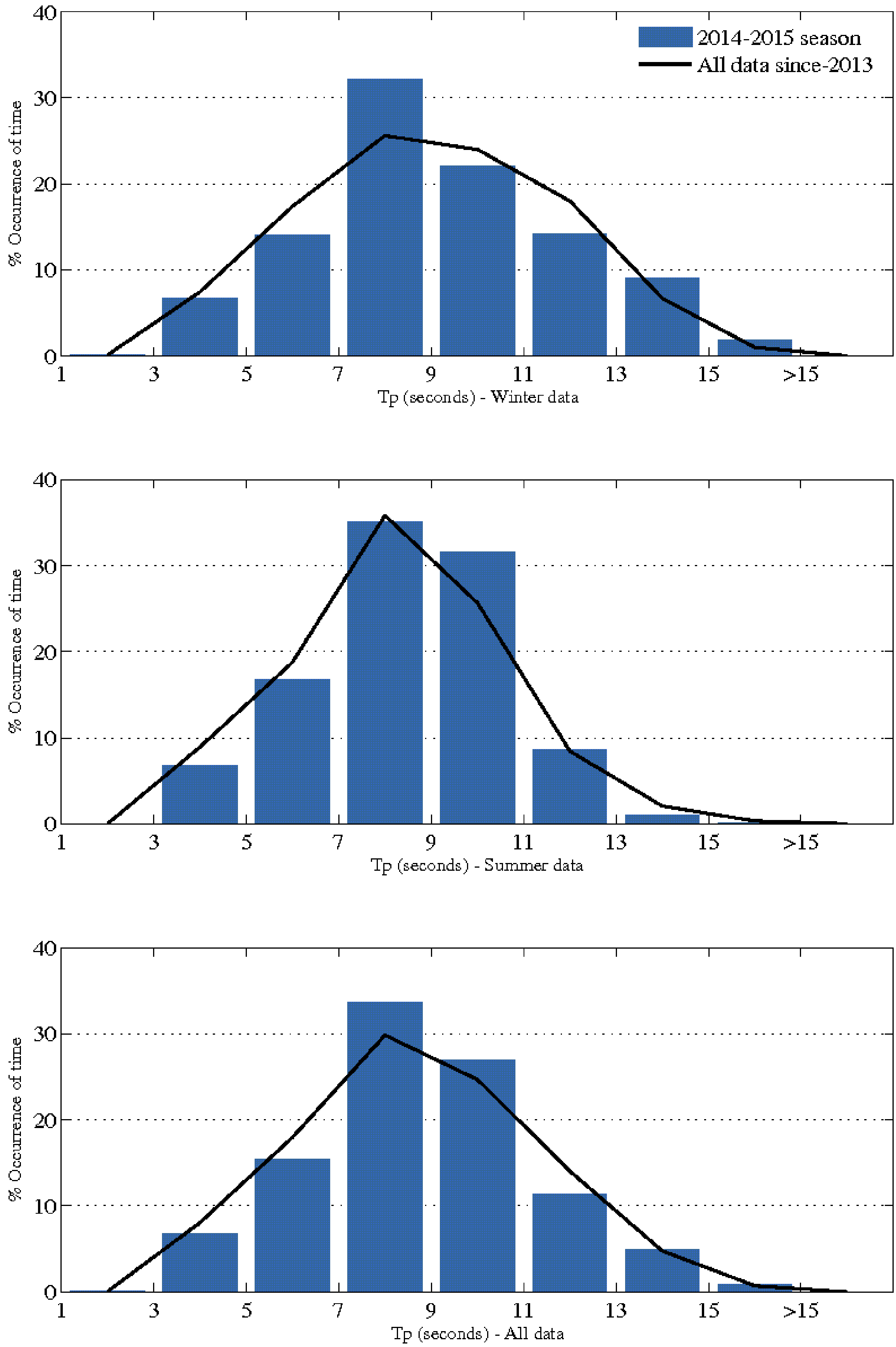


Figure 46 Caloundra – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

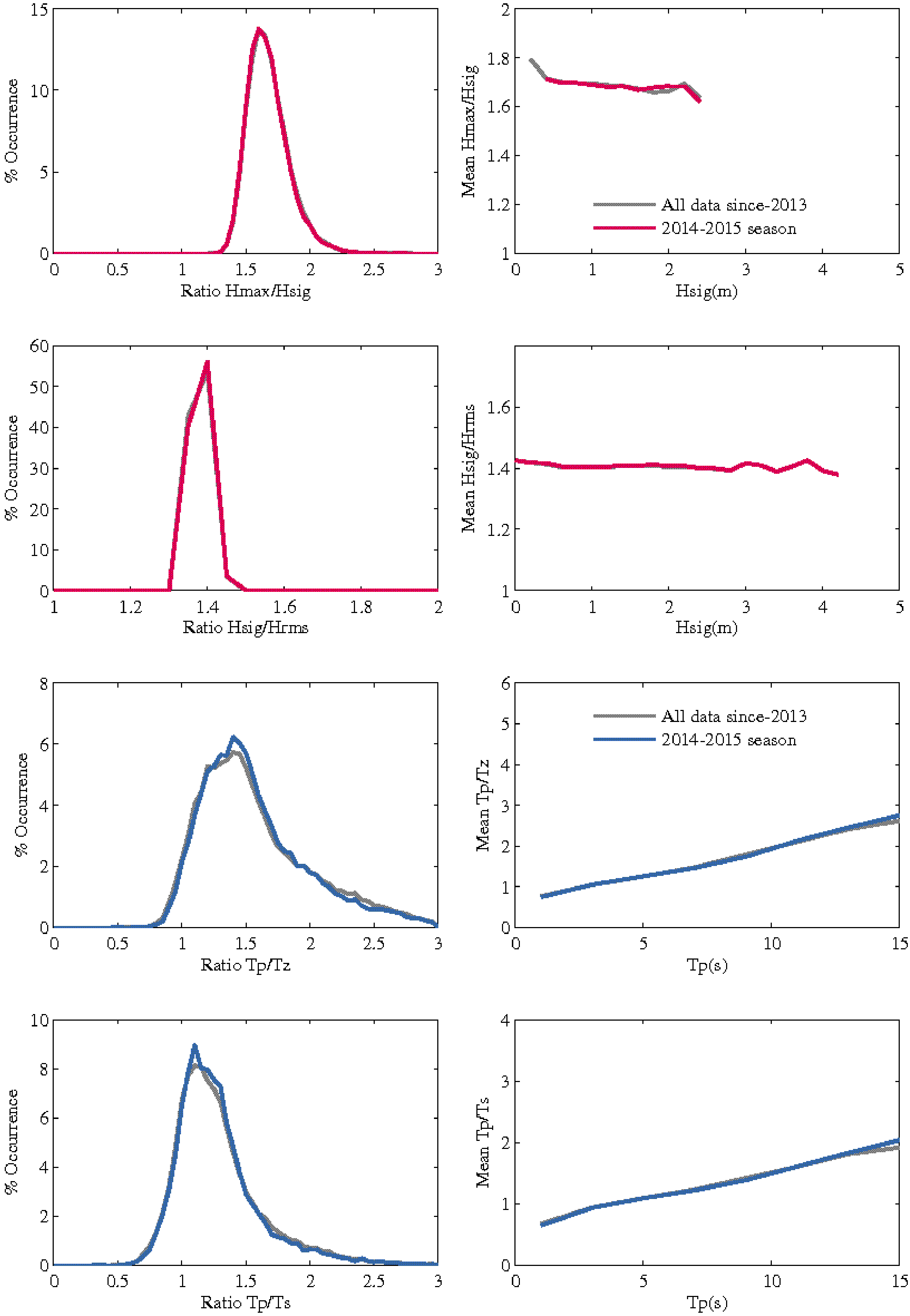
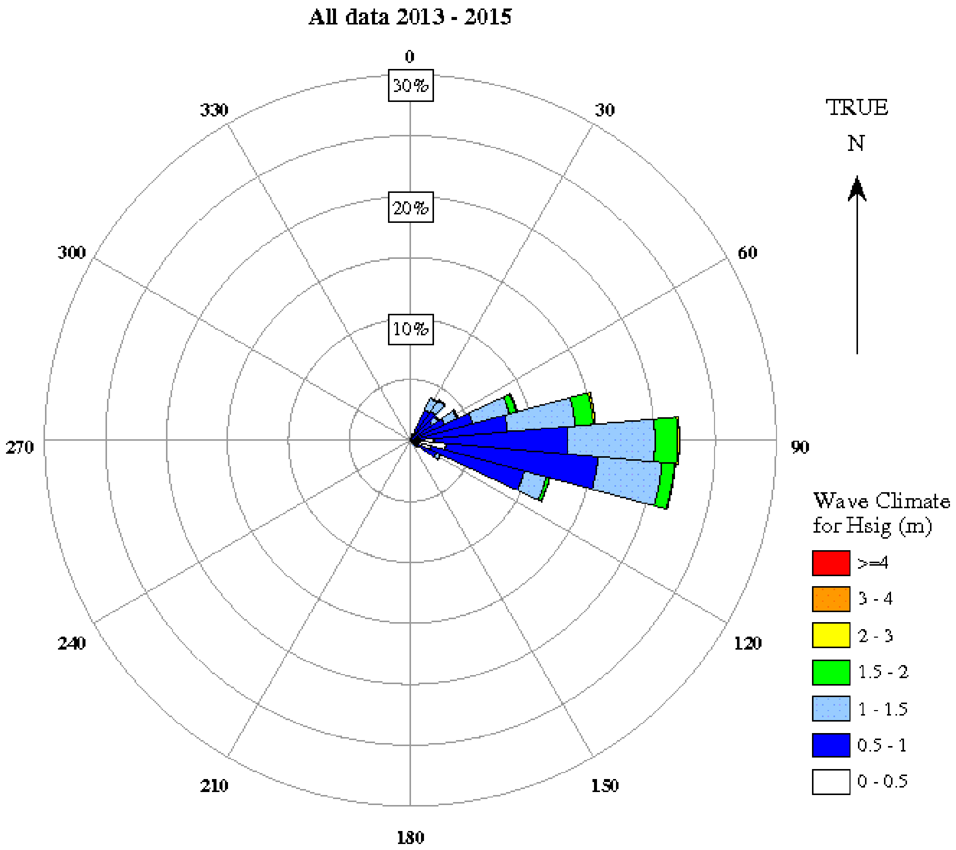


Figure 47 Caloundra – Wave parameter relationships



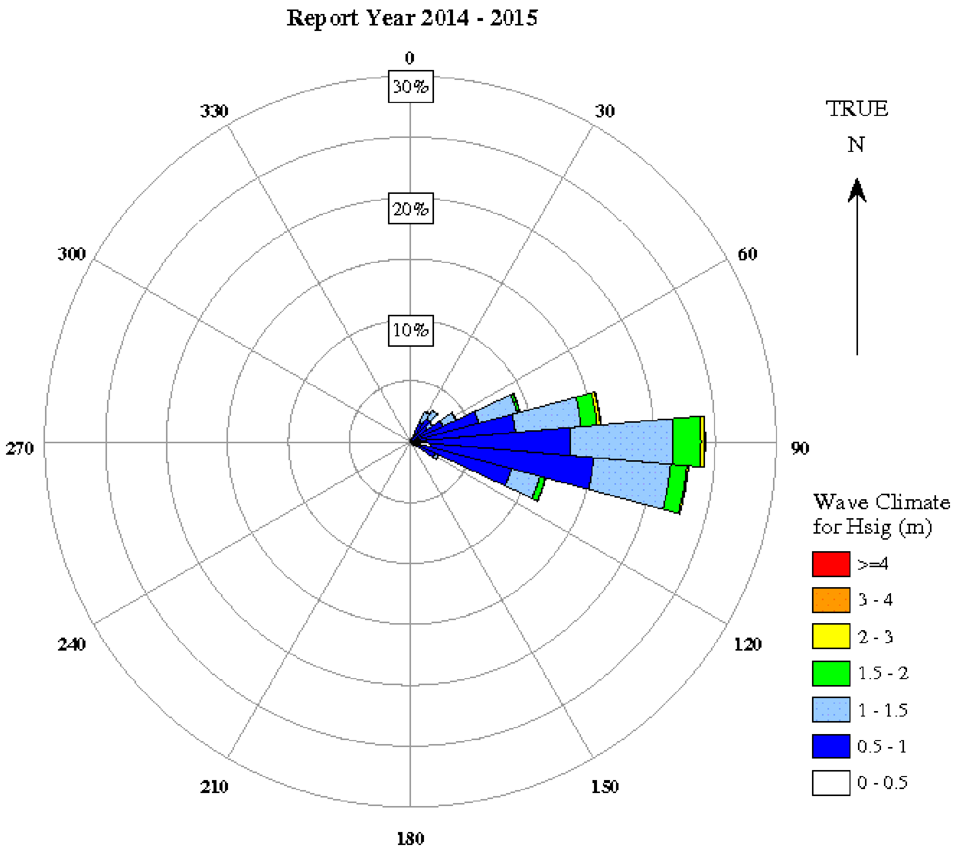


Figure 48 Caloundra – Wave rose

7.6 Mooloolaba

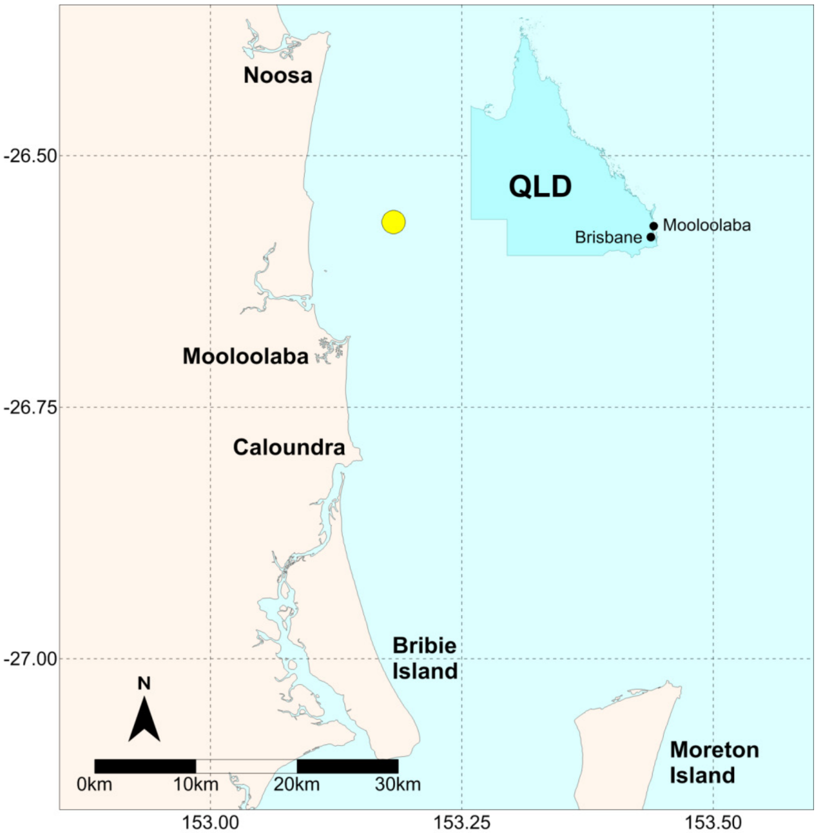


Figure 49 Mooloolaba – Locality plan

Table 25 Mooloolaba – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2000	0.83 years	251,926	14.7
2014–15	01/11/2014	13.31 days	16,880	1

Table 26 Mooloolaba – Buoy deployments for 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°33.960' S	153°10.870' E	32	16/07/2014	09/07/2015
26°33.961' S	153°10.930' E	32	09/07/2015	current

7.6.1 Mooloolaba – seasonal overview

The Mooloolaba wave buoy has been operational for over 15 years with an overall data return of 94.4 percent. The data record for the period November 2014 to October 2015 was good, with total gaps of 13.31 days, equivalent to 96.4 percent data return. The buoy was replaced once during the reporting period on 09 July 2015.

Increases in wave height occurred during February as a result of TC Ola and TC Marcia (Table 27). An East Coast Low which developed north of Fraser Island generated the highest waves recorded at Mooloolaba for the reporting period on 01 May ranking at fourth for the overall wave record (Table 26) with a significant wave height (Hsig) of 5.2 m and a maximum wave height (Hmax) of 9.2 metres. Peaks in wave heights can be seen from these events in the time series for daily wave recordings (Figure 50).

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 end of December to early April was warm enough for tropical cyclone development.

The monthly average Hsig for the recording period fell within one standard deviation (sd) of the entire record except for February and September which both exceeded +1 sd (Figure 52). The deviation in February is due to the extended influence of TC Ola and TC Marcia during the month.

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 mid-range wave heights from 1.0–1.4 m for the reporting period. Histograms of the occurrence of peak wave periods (Tp) (Figure 55) show a greater occurrence of the modal 7–9 seconds Tp range during winter and greater occurrence of the 9 to 11 seconds Tp during summer for the reporting period compared to 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 56.

Time series for wave direction (Figure 51) shows waves predominantly from the southeast to northeast. The directional wave rose plots (Figure 57) support this too. The wave directions for the reporting period are very similar to the entire record.

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	28/06/2012 04:30	7.9
10	28/06/2012 07:00	4.3	02/02/2001 06:00	7.6

Table 28 Mooloolaba – Significant meteorological events with threshold Hsig of 2.6 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
12/12/2014 20:00	2.7 (3.0)	4.4 (5.0)	7.6	A complex low over southern Queensland resulted in an east coast low.
4/02/2015 20:30	2.8 (2.9)	4.7 (5.5)	11.0	Tropical Cyclone Ola passed into the Coral Sea.
18/02/2015 9:30	3.0 (3.3)	5.4 (6.2)	10.2	TC Marcia formed on the 18th off the central coast of Queensland and intensified over the following days whilst tracking south to deteriorate into a low off the southeast Queensland coast.
1/05/2015 15:30	4.7 (5.2)	7.2 (9.2)	10.8	An East Coast Low developed north of Fraser Island, bringing heavy rain, powerful surf and damaging winds to much of southeast 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.

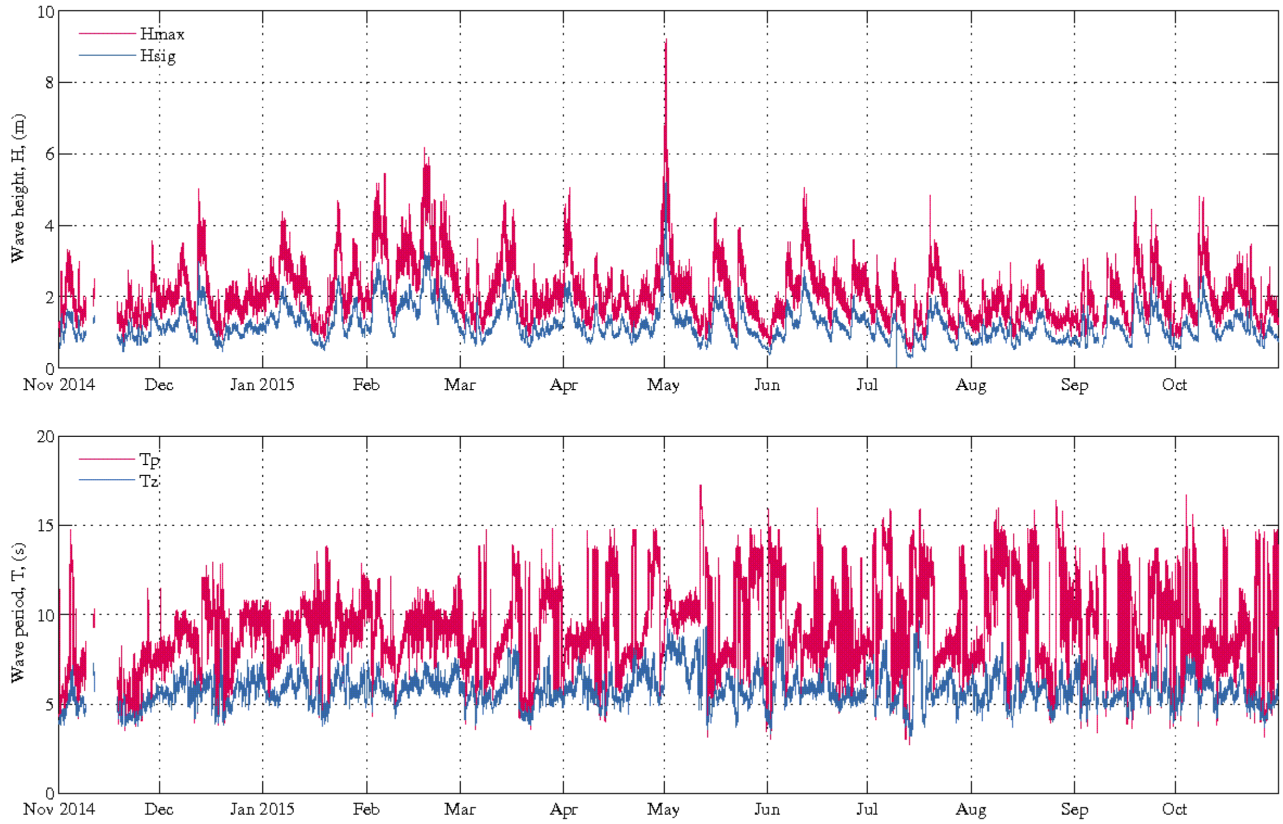


Figure 50 Mooloolaba – Daily wave recordings

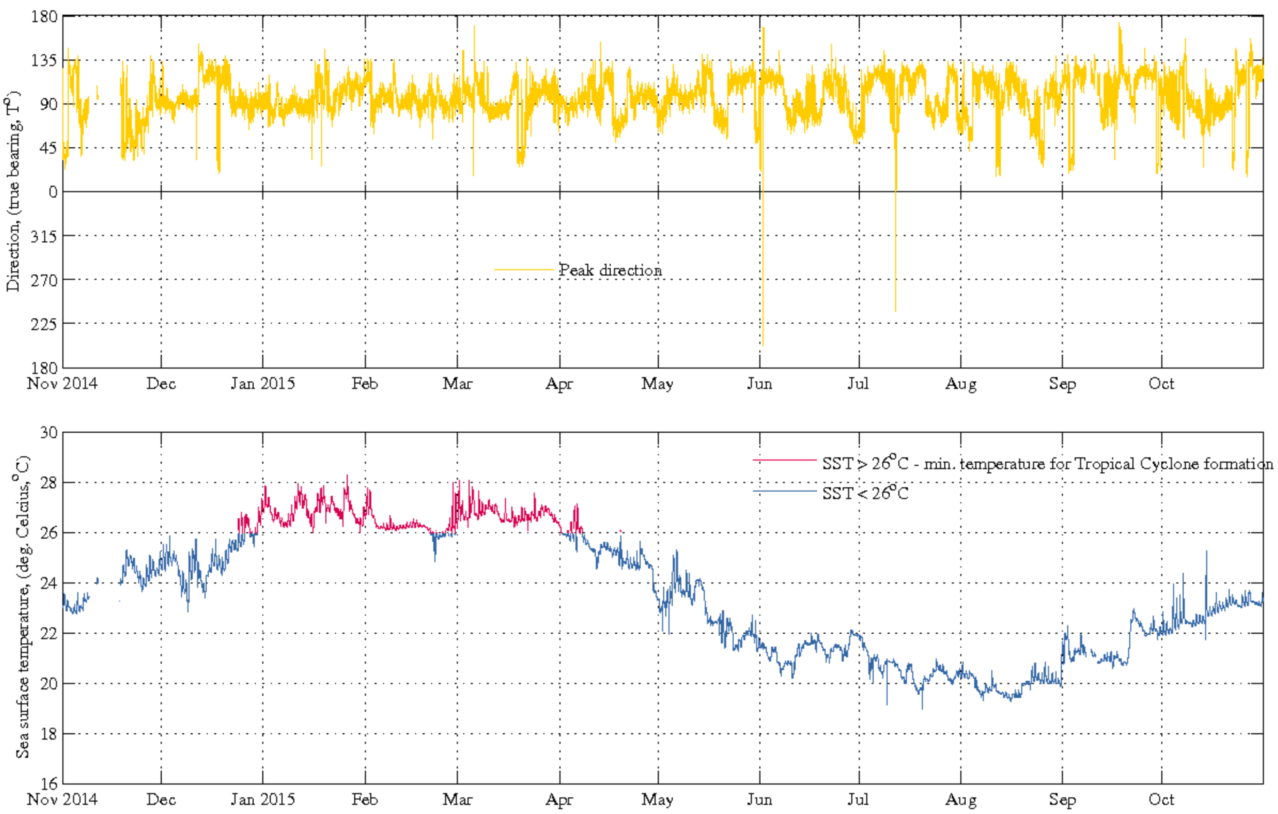


Figure 51 Mooloolaba – Sea surface temperature and peak wave directions

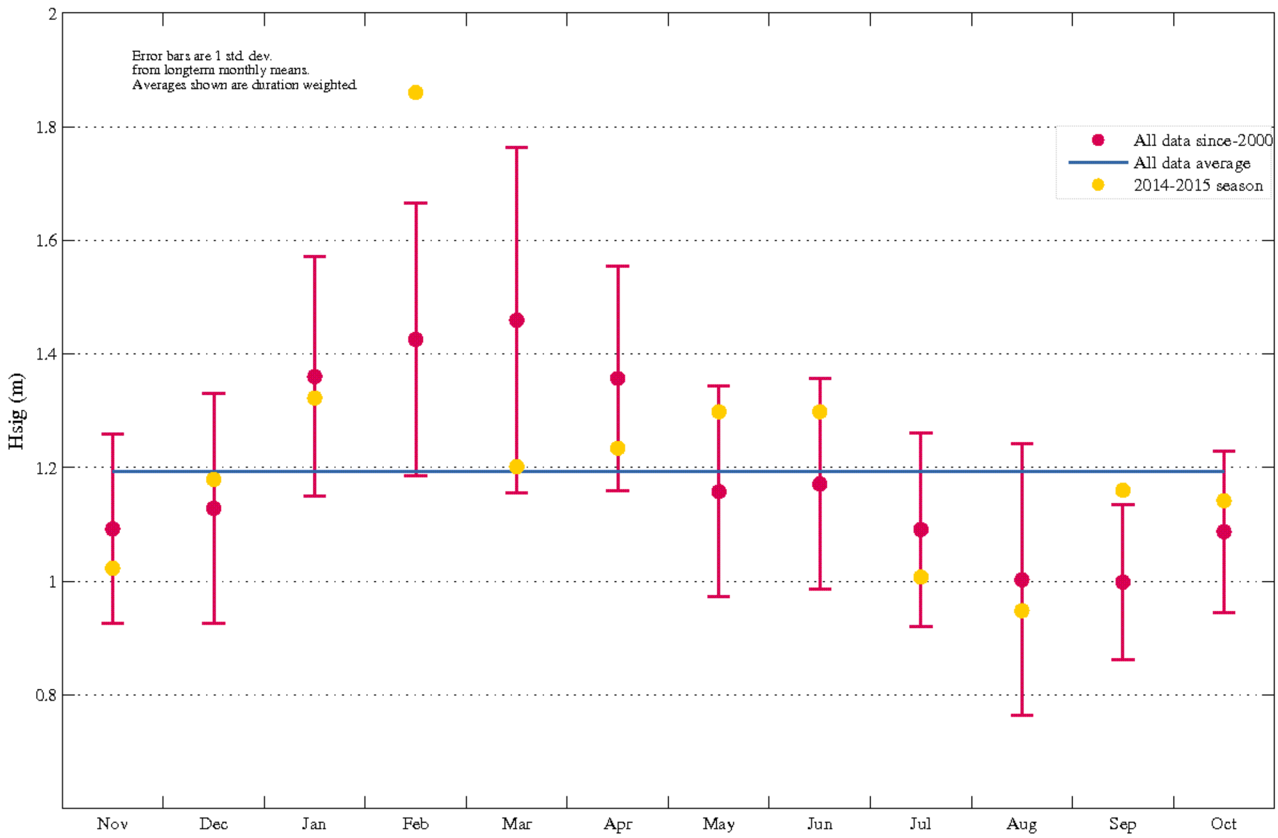


Figure 52 Mooloolaba – Monthly average wave height (Hsig) for seasonal year and for all data

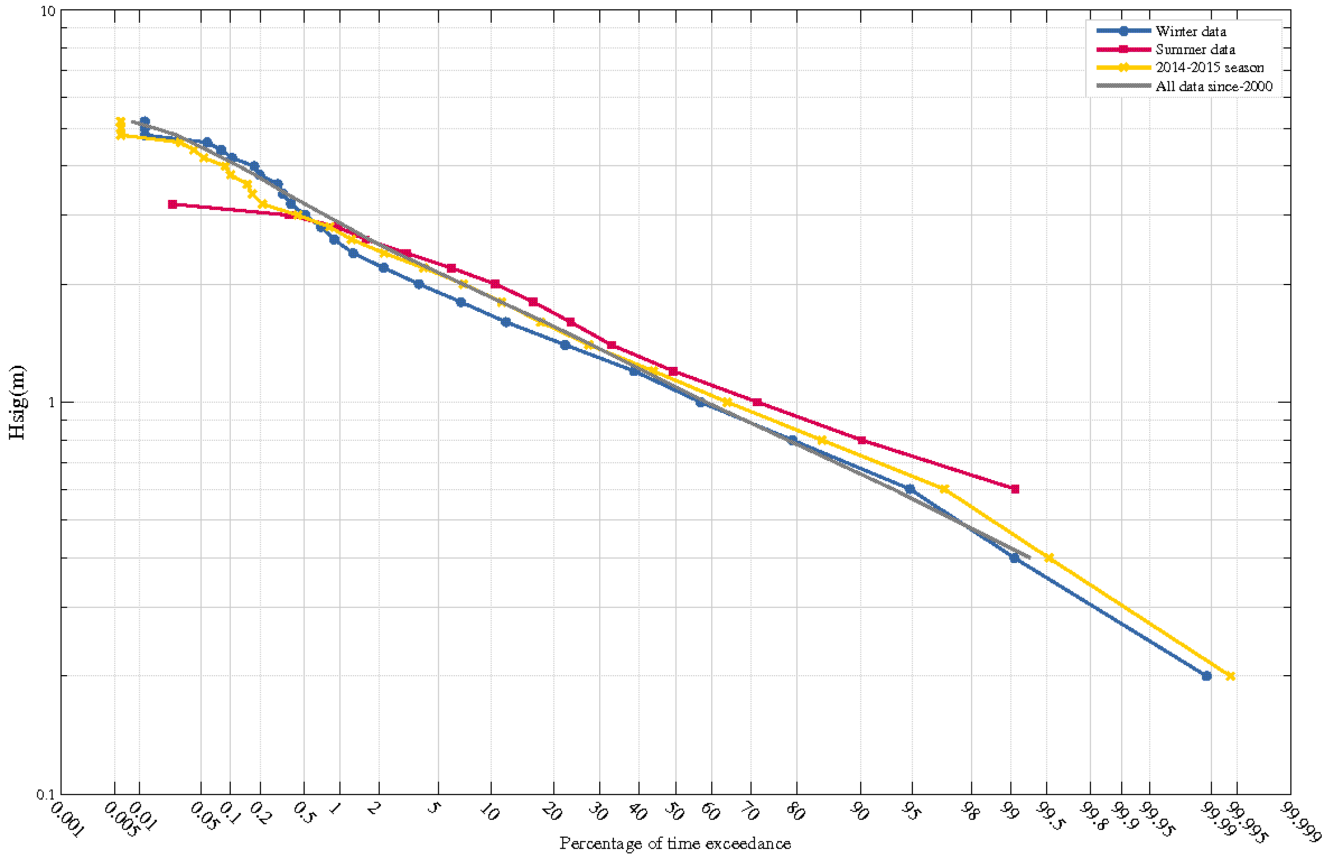


Figure 53 Mooloolaba – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

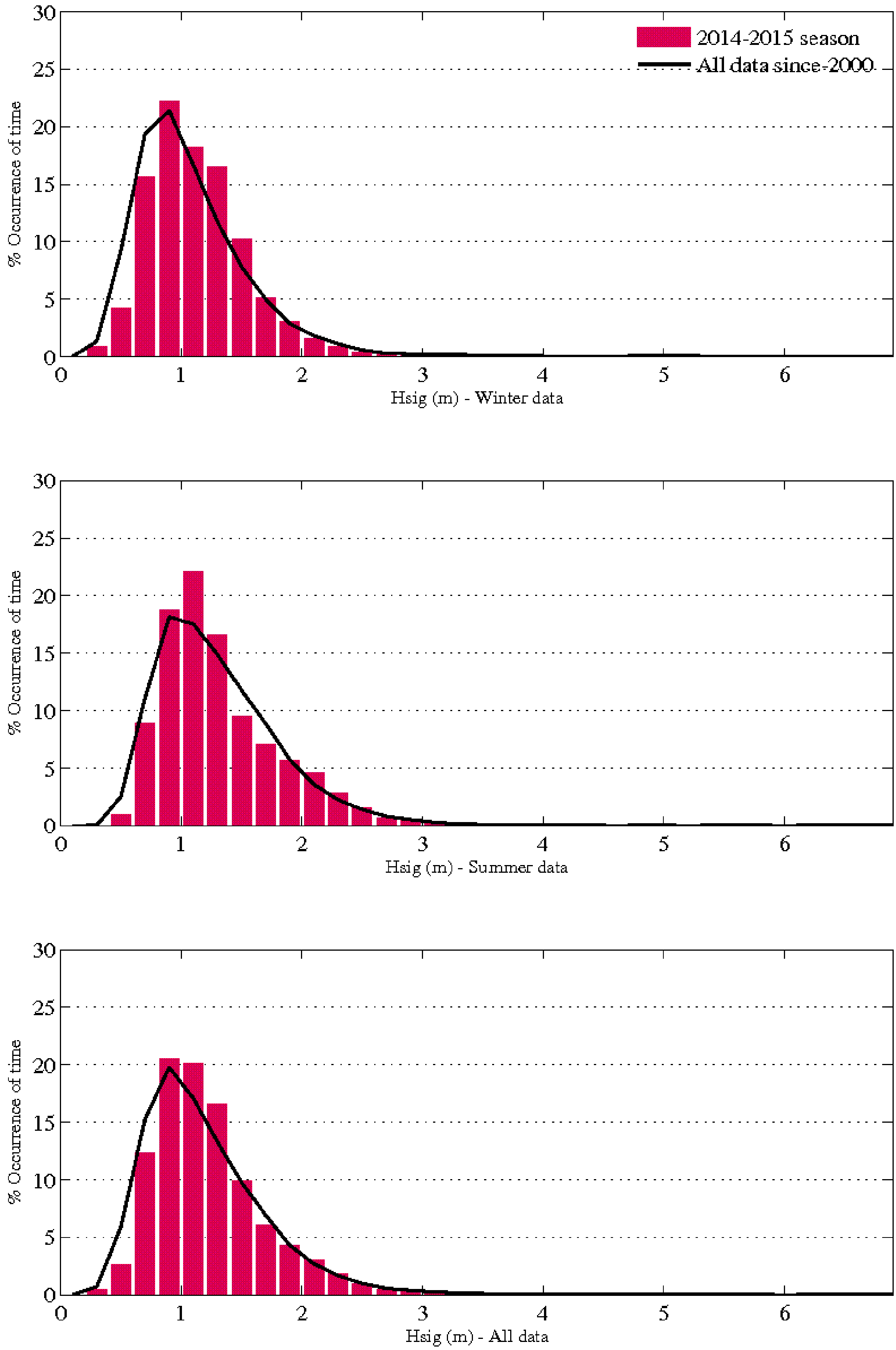


Figure 54 Mooloolaba – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

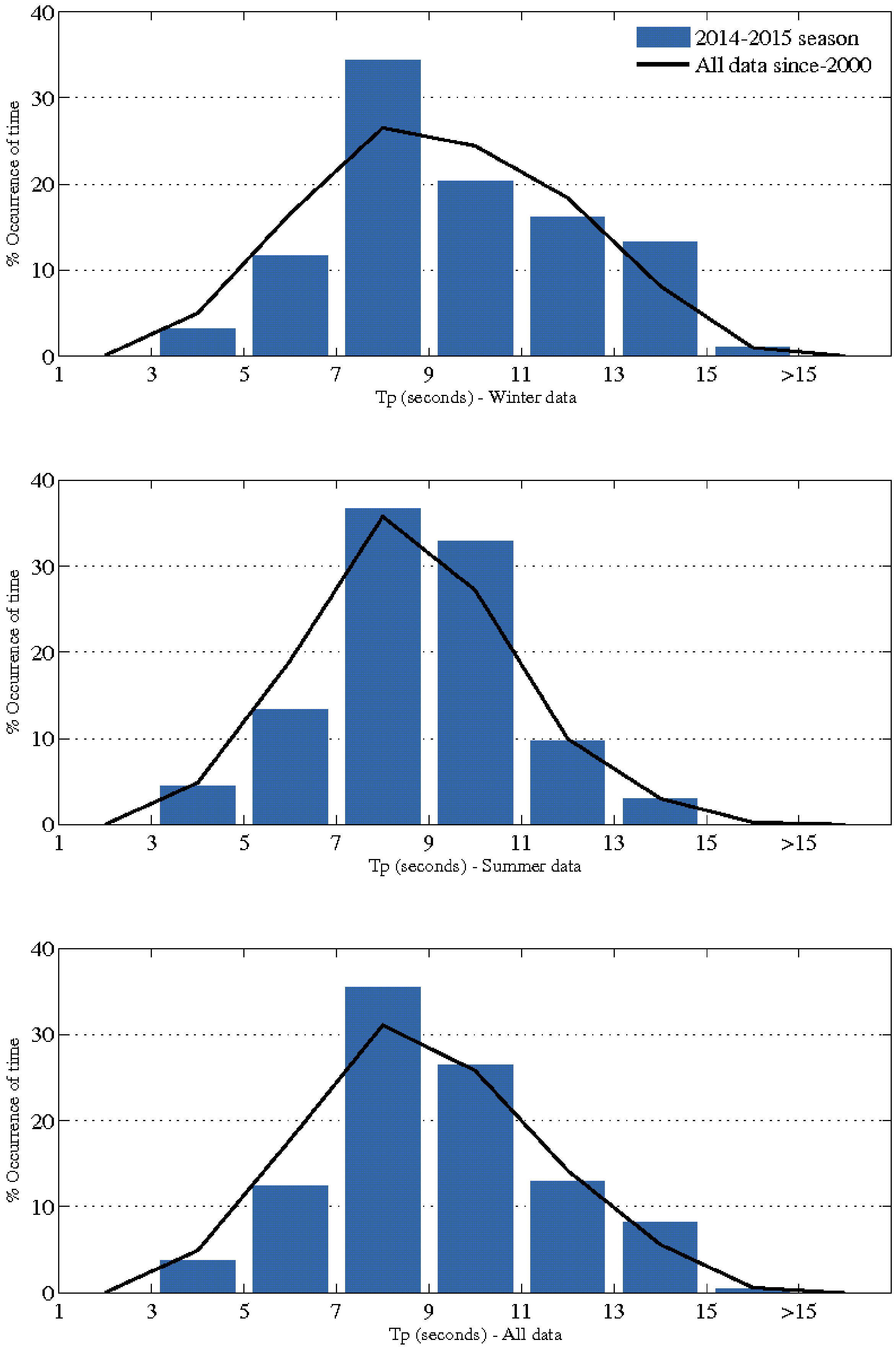


Figure 55 Mooloolaba – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

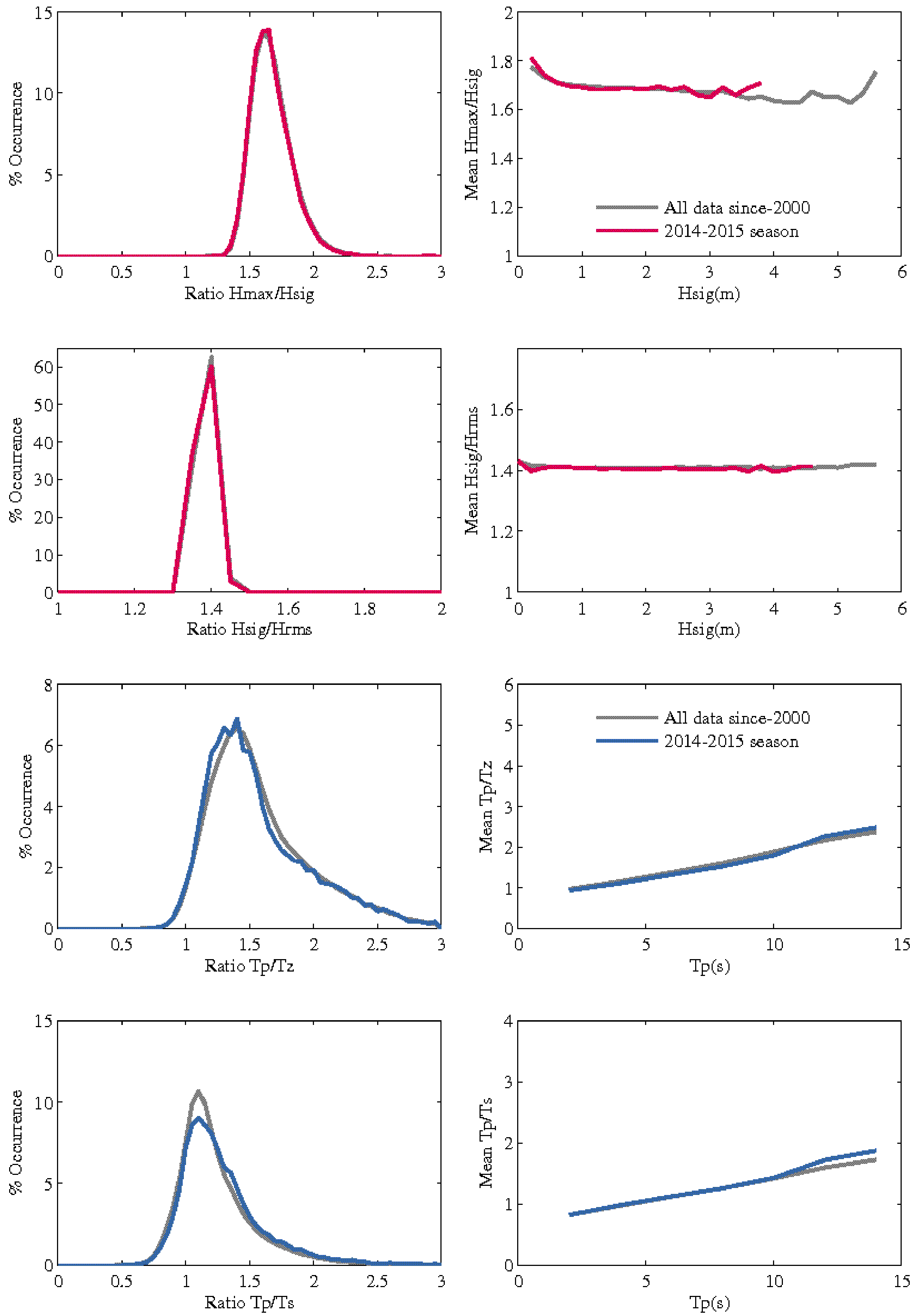


Figure 56 Mooloolaba – Wave parameter relationships

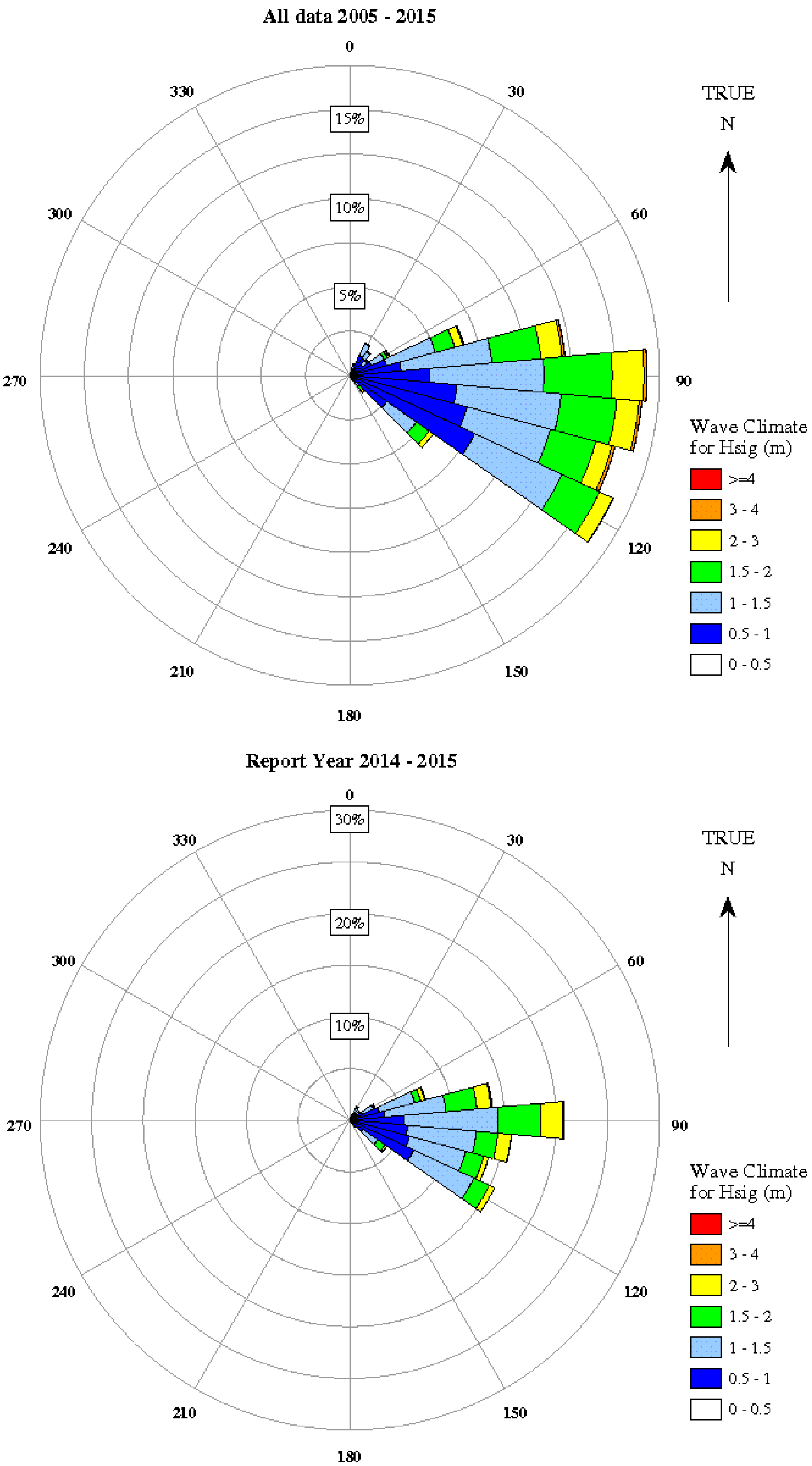


Figure 57 Mooloolaba – Directional wave rose

7.7 Gladstone

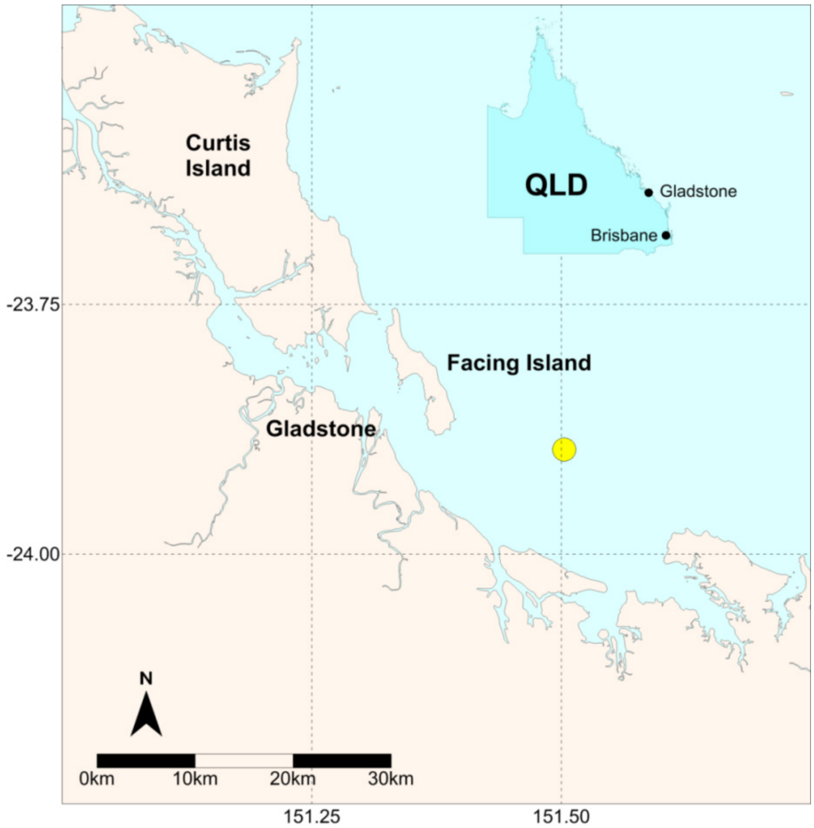


Figure 58 Gladstone – Locality plan

Table 29 Gladstone wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	23/09/2009	0.16 years	103,903	6.1
2014–15	01/11/2014	7.48 days	17,160	1

Table 30 Gladstone – Buoy deployments during the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
23°53.695' S	151°30.101' E	16.5	26/09/2014	27/07/2015
23°53.683' S	151°30.084' E	14	27/07/2015	current

7.7.1 Gladstone – seasonal overview

The Gladstone wave buoy has been operational for six years with an overall data return of 97.4 per cent. The data recorded for the period November 2014 to October 2015 was good, with total gaps of 7.48 days, equivalent to a 98.0 per cent data return. The buoy was replaced once during the reporting period on 27 July (Table 29).

TC Marcia passed inland of the Gladstone coast as it declined from a category 3 to category 1 tropical cyclones (Table 32). This generated a significant wave height (Hsig) of 3.0 m and a maximum wave height (Hmax) of 5.5 metres. This event ranked at third for Hsig and fourth for Hmax in the highest recorded waves at the site (Table 31).

The temperature (sea surface temperature, SST) measured in the buoy hull showed a range of 10° C to 25° C (Figure 60) however the SST from November 2014 to 27 July 2015 reported 6.8 degrees lower than expected. There was a brief outage of the SST measurement during later July.

The monthly average Hsig for the recording period was exceeded by one standard deviation (sd) in four months throughout the reporting period (Figure 61). December and March had exceedances of −1 sd and February and June had exceedances of +1 sd.

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 (Figure 62). The wave climate during summer generally experiences larger waves than the winter. Histograms of the occurrence of Hsig (Figure 63) show a greater occurrence of 0.4–0.6 m waves during the summer of the reporting period compared to the entire record and this is also reflected in the overall distribution. Histograms of the occurrence of peak wave periods (Tp) (Figure 64) show a similar distribution between the recent period and the whole record but with a greater occurrence of 7 to 9 secomds Tp waves during winter.

The ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data (Figure 65).

Time series for wave direction (Figure 60) shows wave directions predominately from the east-northeast with occasional swings to the north during summer and to the south during winter. This is also seen in the direction wave rose plots (Figure 66). The wave directions for the reporting period were very similar to the entire record.

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	01/02/2014 01:00	2.8	20/02/2015 16:30	5.5

5	20/03/2010 10:30	2.3	20/03/2010 21:30	4.7
6	16/01/2012 22:00	2.3	16/01/2012 22:30	4.5
7	12/04/2013 04:00	2.3	12/04/2013 05:00	3.9
8	12/10/2010 12:00	2.2	12/10/2010 11:00	3.8
9	13/03/2010 13:30	2.1	13/03/2010 14:00	3.8
10	08/01/2014 22:00	1.9	8/01/2014 22:00	3.2

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
20/02/2015 15:00	2.9 (3.0)	4.9 (5.5)	9.1	Tropical Cyclone Marcia passed inland of the Gladstone coast as it declined from a category 3 to a category 1 tropical cyclone.

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.

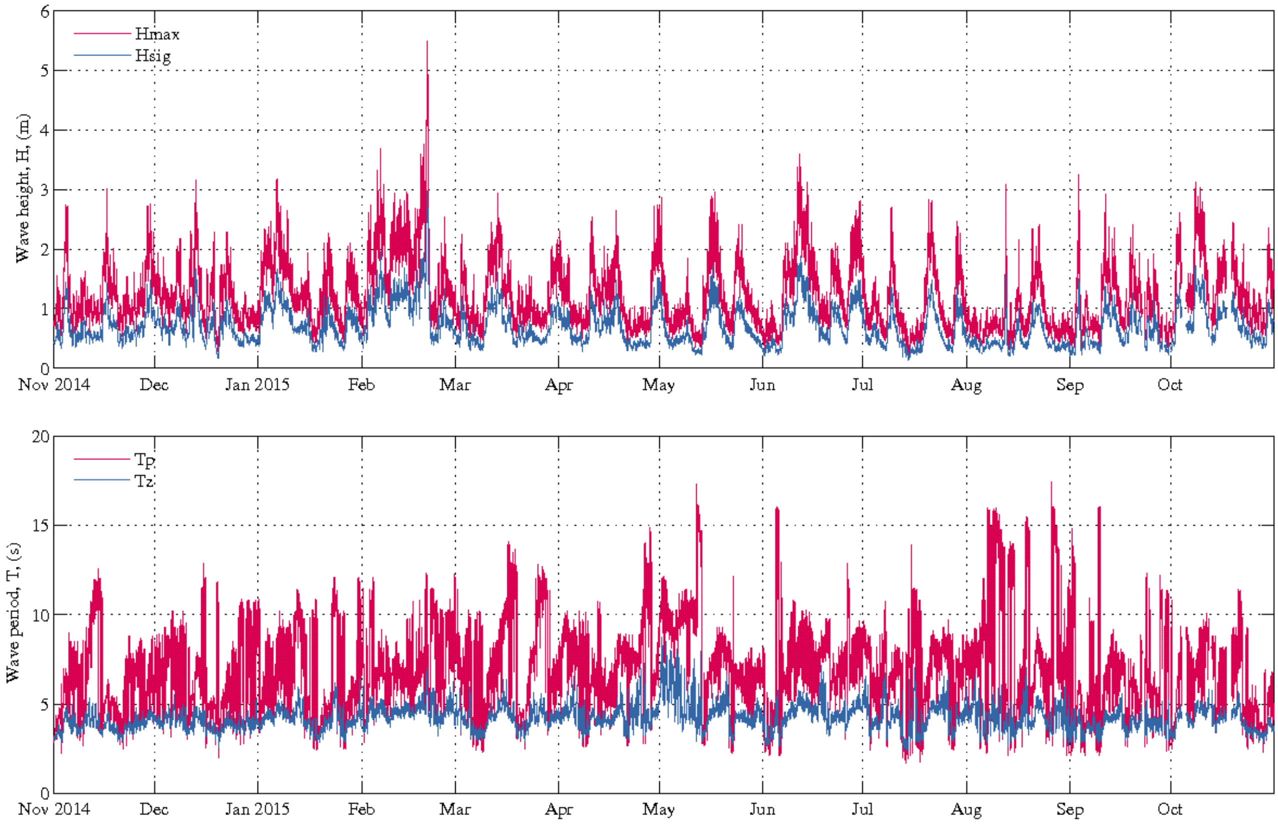


Figure 59 Gladstone – Daily wave recordings

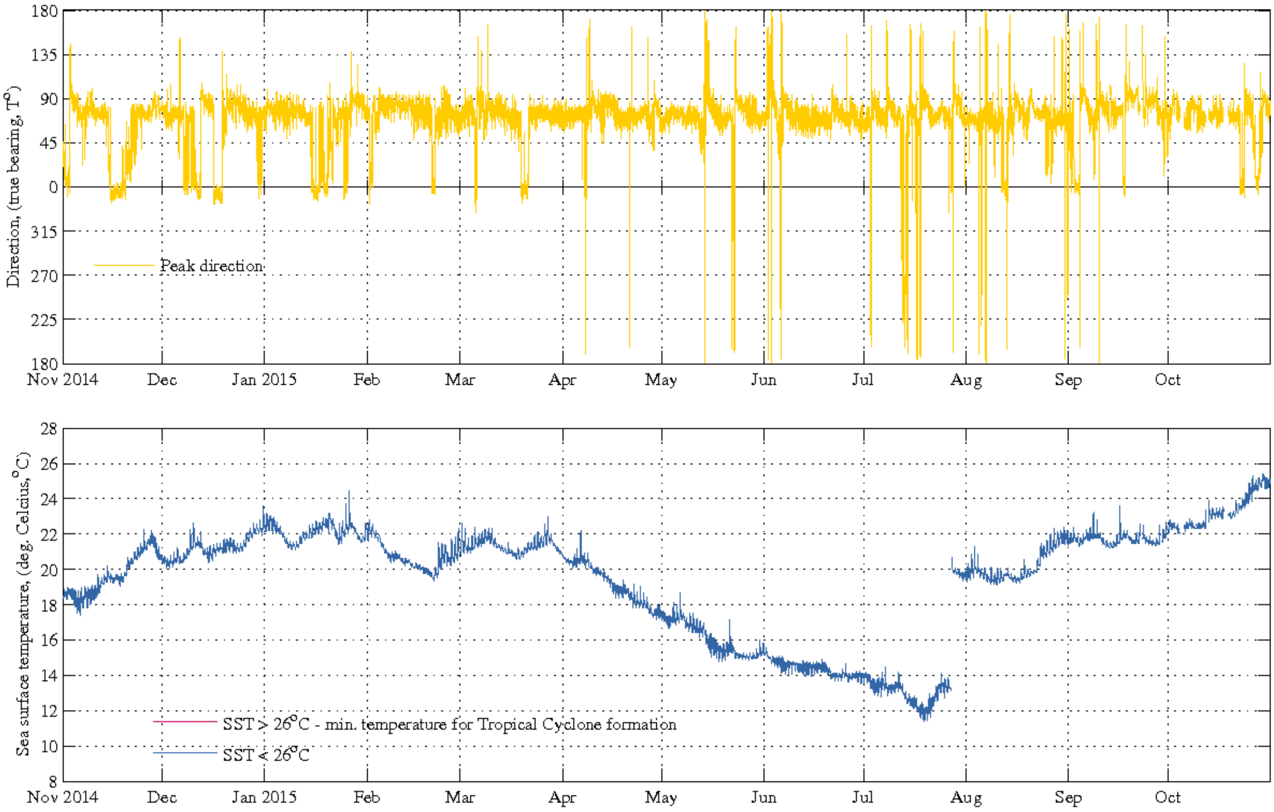


Figure 60 Gladstone – Sea surface temperature and peak wave directions

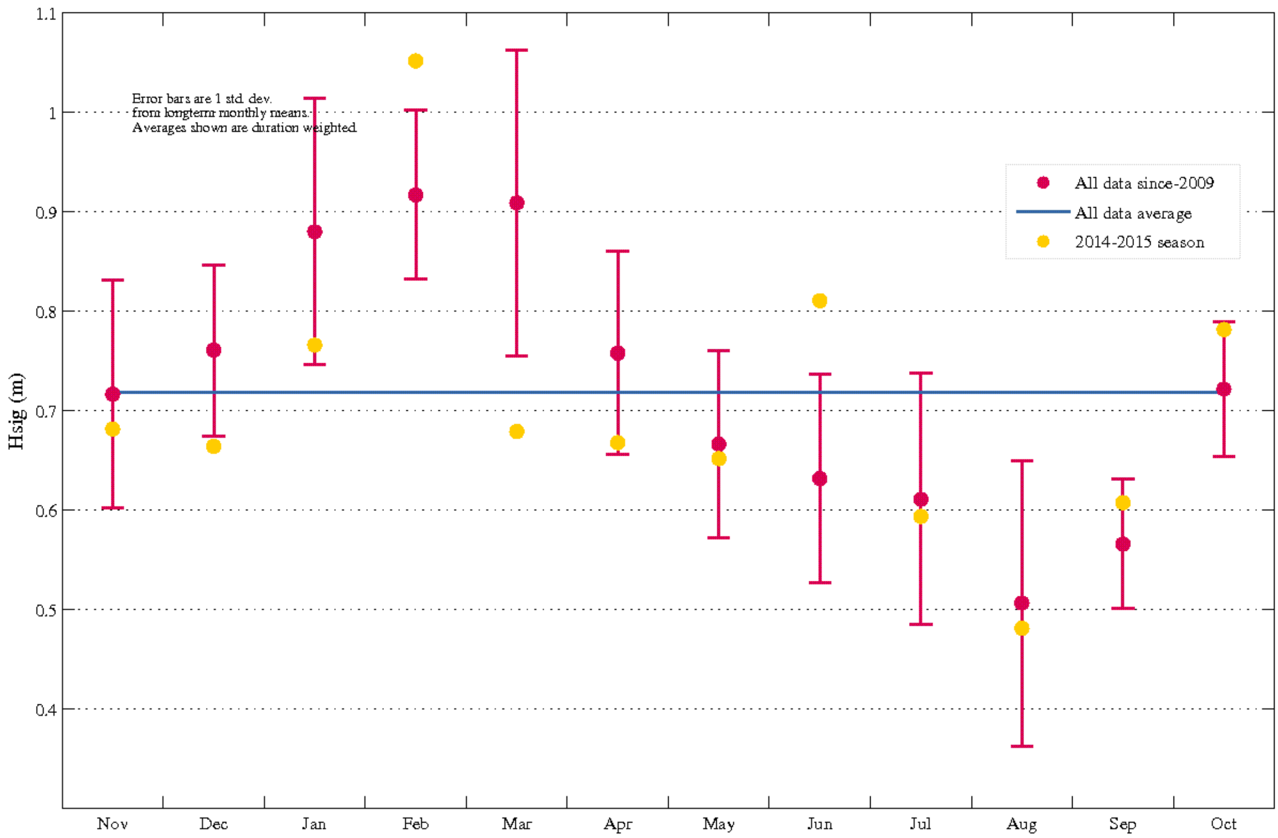


Figure 61 Gladstone – Monthly average wave height (Hsig) for seasonal year and for all data

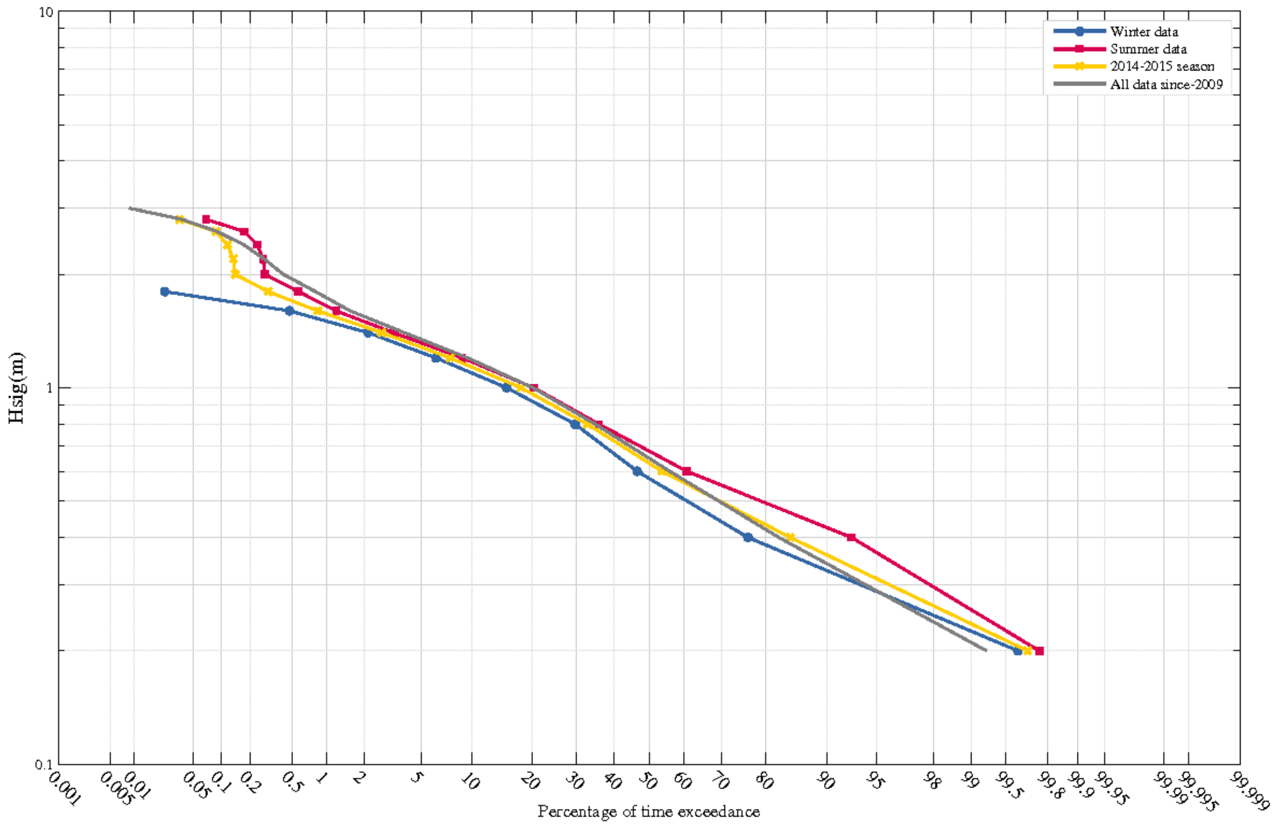


Figure 62 Gladstone – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

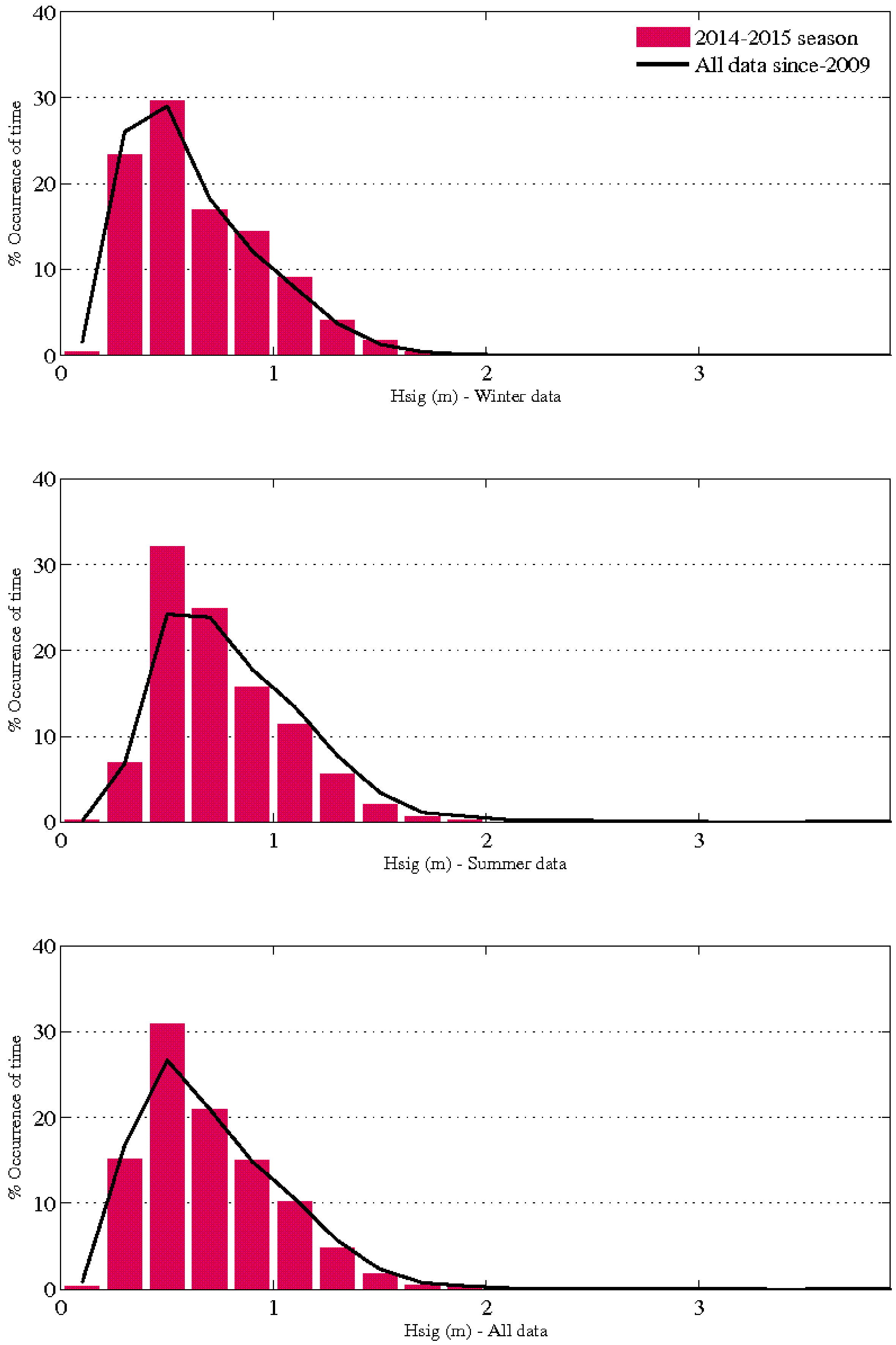


Figure 63 Gladstone – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

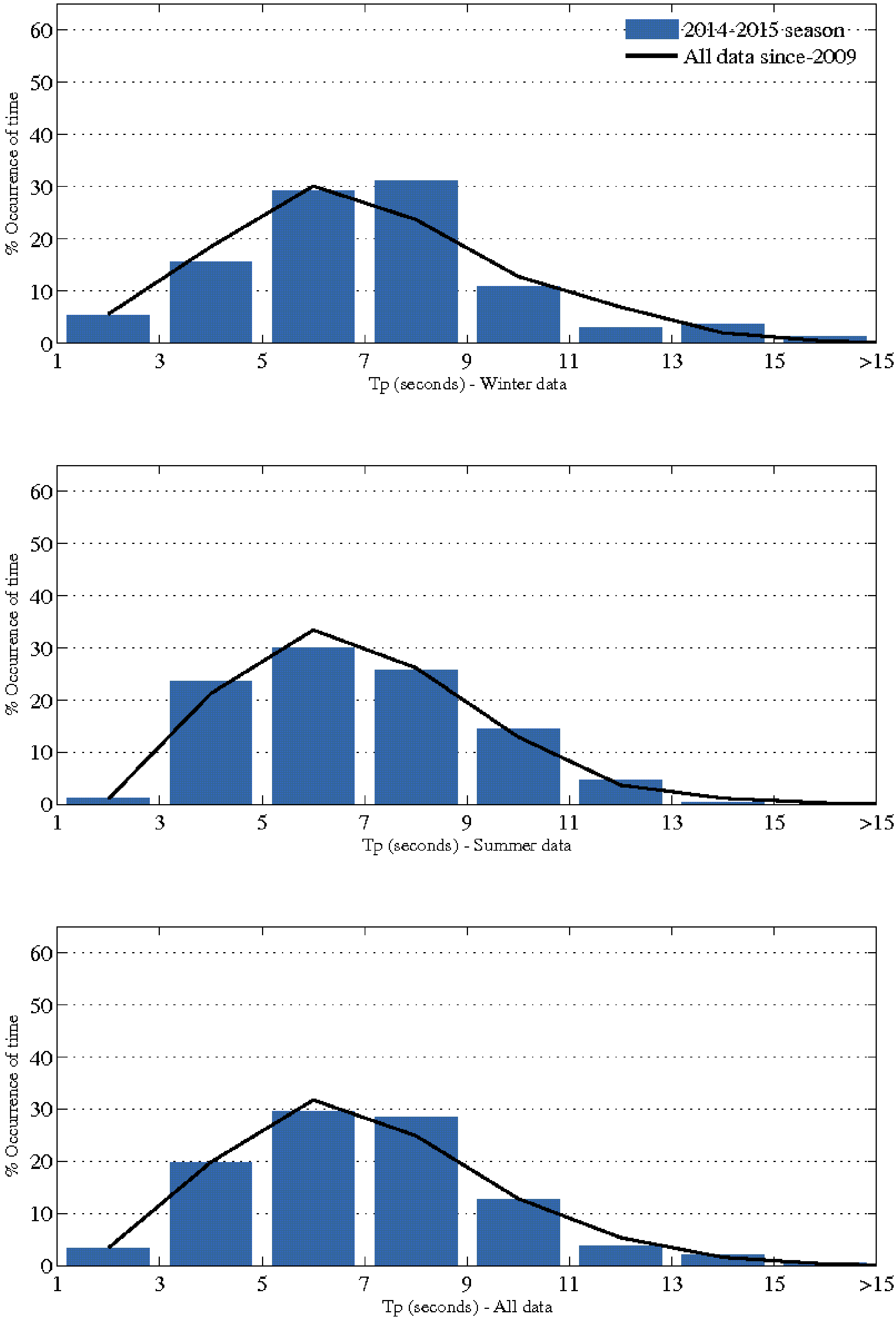


Figure 64 Gladstone – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

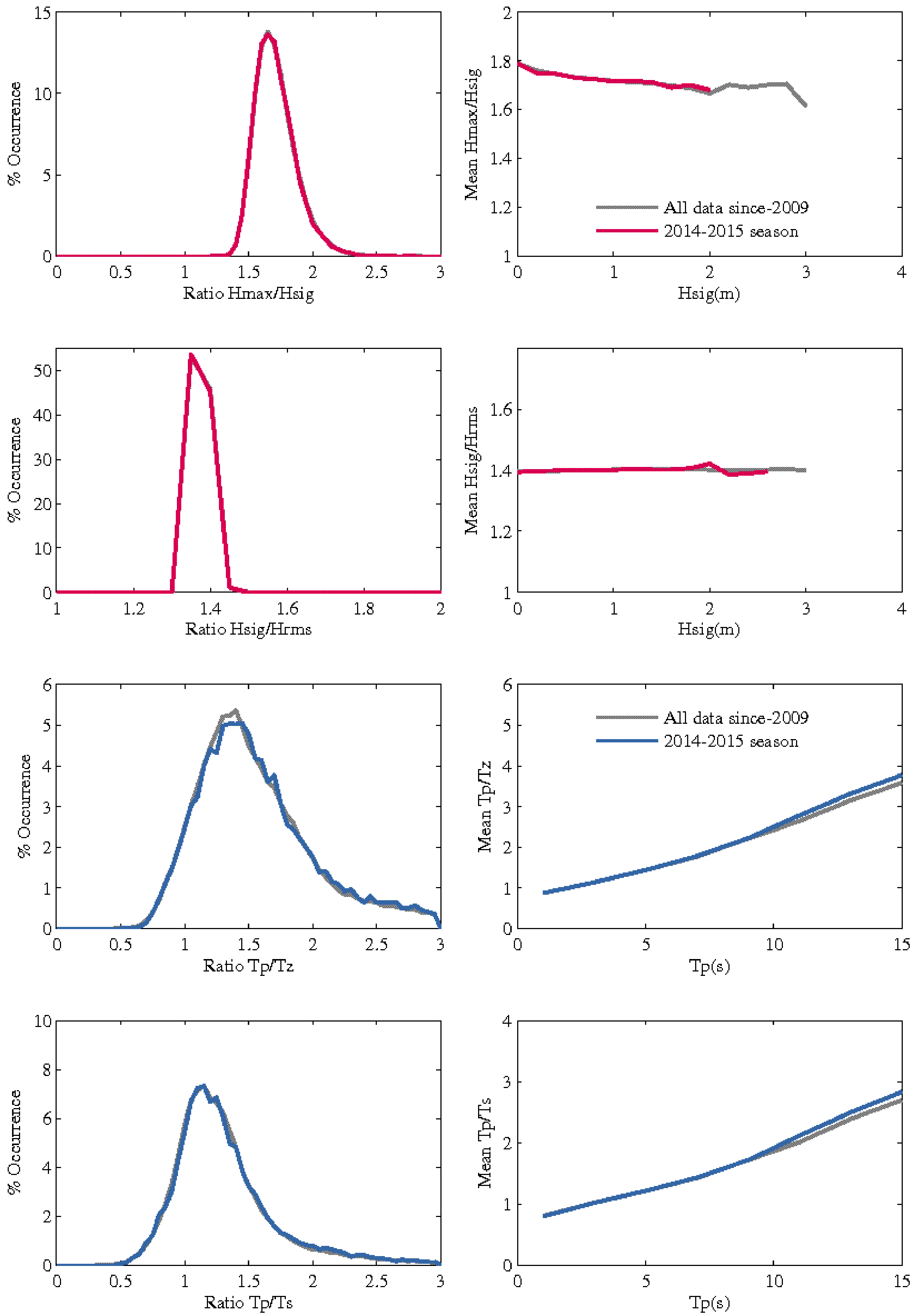
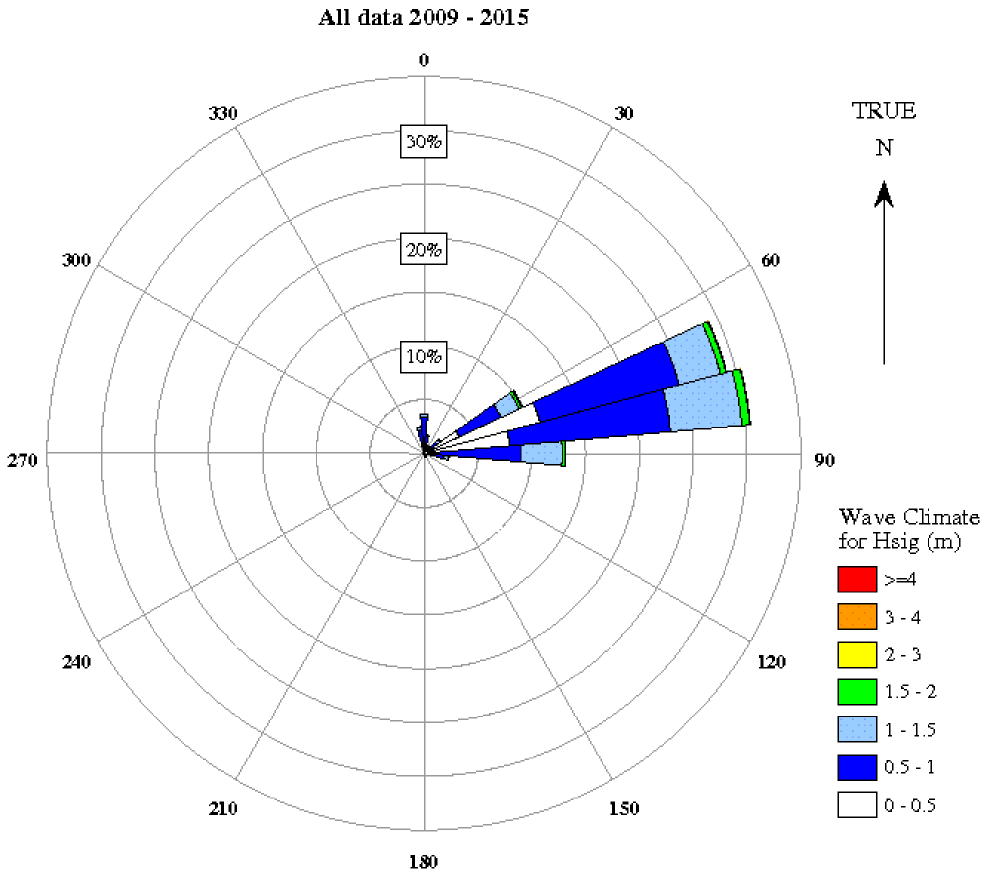


Figure 65 Gladstone – Wave parameter relationships



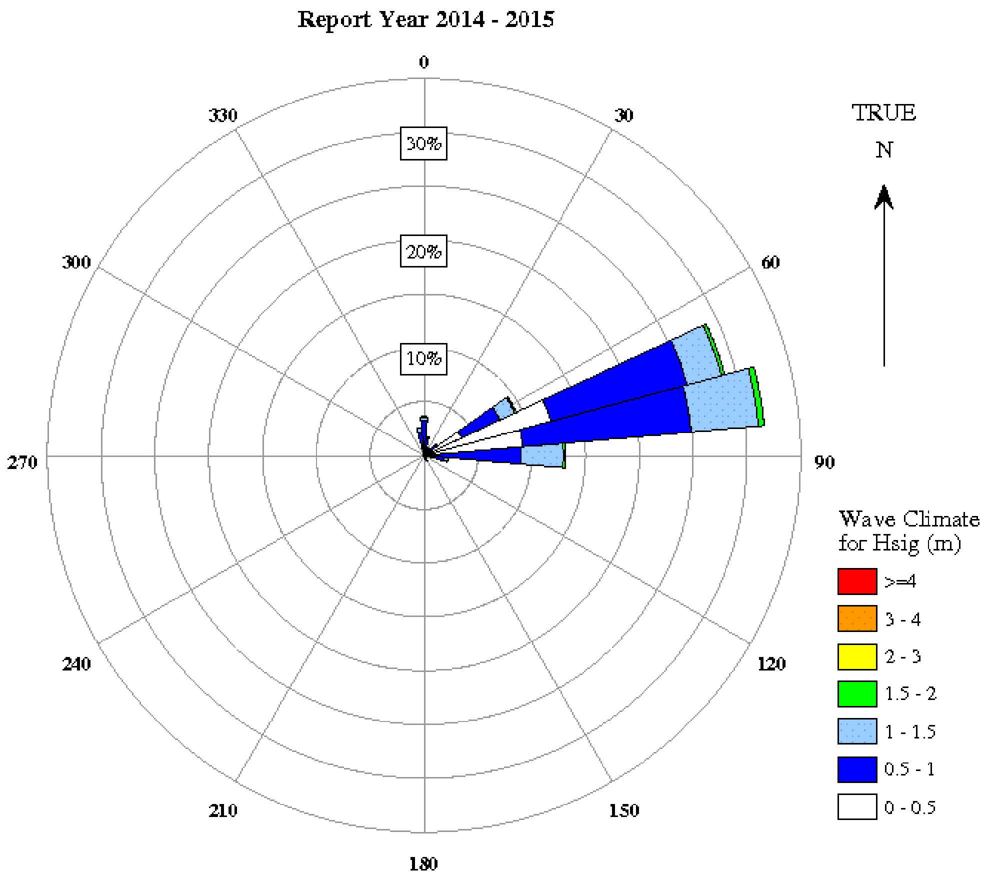


Figure 66 Gladstone – Directional wave rose

7.8 Emu Park

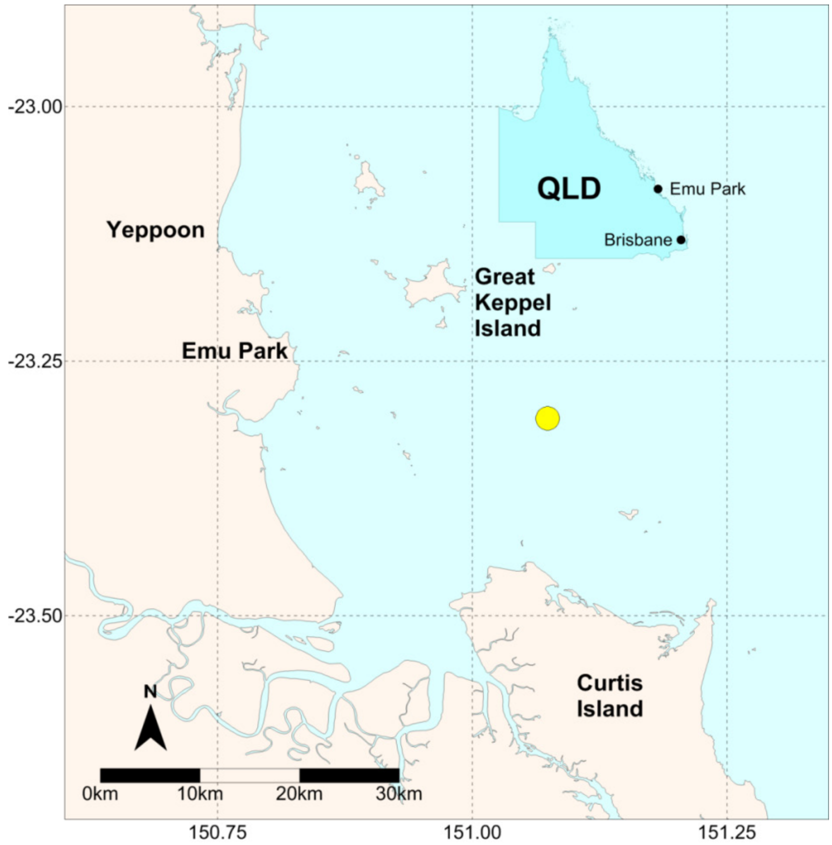


Figure 67 Emu Park – Locality plan

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	270,755	19.3
2014–15	01/11/2014	8.08 days	17,131	1

Table 34 Emu Park – Buoy deployments during the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°18.314' S	151°04.275' E	19	23/05/2014	current

7.8.1 Emu Park – seasonal overview

The Emu Park wave buoy has been operational for just over 19 years with an overall data return of 95.2 per cent. The data recorded for the period November 2014 to October 2015 was good, with total gaps of 8.08 days, equivalent to 97.8 percent data return (Table 33). The buoy hasn't been replaced during the reporting period (Table 34).

The highest significant wave height (Hsig) and the third highest maximum wave height (Hmax) were recorded on 20 February during TC Marcia (Table 35). Hsig and Hmax reached respectively 4.0 m and 7.0 m during this event and is the most distinguishable spike 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 the winter months, the wave direction occasionally turned to a southern direction. Sea surface temperature (SST) (Figure 69) ranged from 19.5° C to 31° C. SST was high enough for tropical cyclone development throughout summer and for the extended periods in November, March and April.

The monthly average Hsig was outside of one standard deviation (sd) during February, March and June (Figure 70) during the reporting period. February was influenced by TC Marcia (Table 36), and resulted in monthly average above the positive standard deviation, even though there is a transmission failure during this month. The monthly average of the month March is lower than the standard deviation.

Percentage exceedance of Hsig (Figure 71) shows wave heights were greater during summer compared to winter. 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 0.4m–0.6m waves Hsig during the recorded period, this range being the most common Hsig for the reporting period.

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, which is a very similar distribution for the reporting period and entire record.

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	31/01/2014 01:00	3.5	09/03/1997 11:30	6.9
5	28/08/1998 06:30	3.2	31/01/2014 04:00	6.7

6	04/06/2002 13:00	3.2	28/08/1998 08:00	6.4
7	9/03/1997 19:30	3.1	4/06/2002 17:30	6.4
8	20/03/2010 16:00	3	20/03/2010 12:30	5.9
9	09/03/2009 01:30	3	4/03/2003 11:30	5.9
10	23/04/2000 20:30	3	26/02/2010 01:00	5.9

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
20/02/2015 13:30	3.8 (4.0)	6.0 (7.0)	8.4	Tropical Cyclone Marcia passed inland of the coast as it declined from a category 3 to a category 1 tropical cyclone

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.

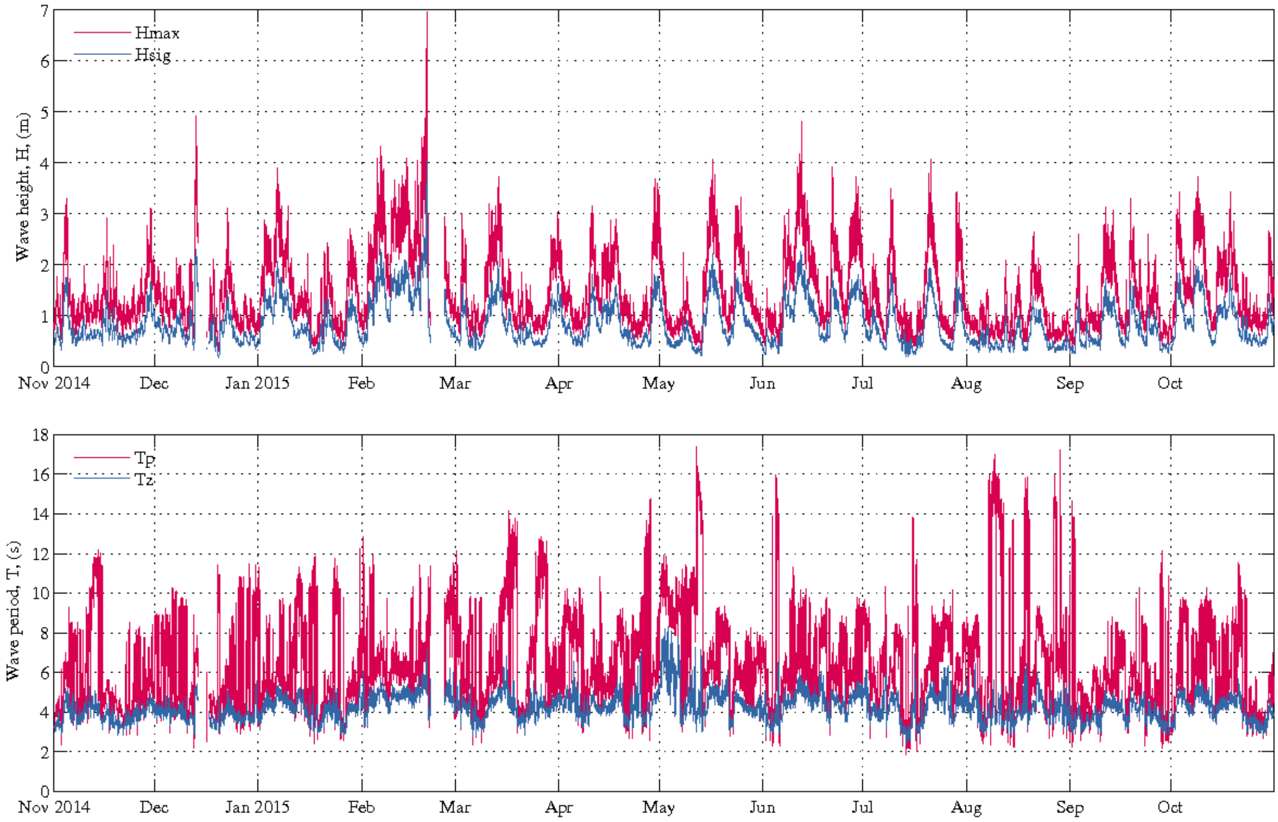


Figure 68 Emu Park – Daily wave recordings

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

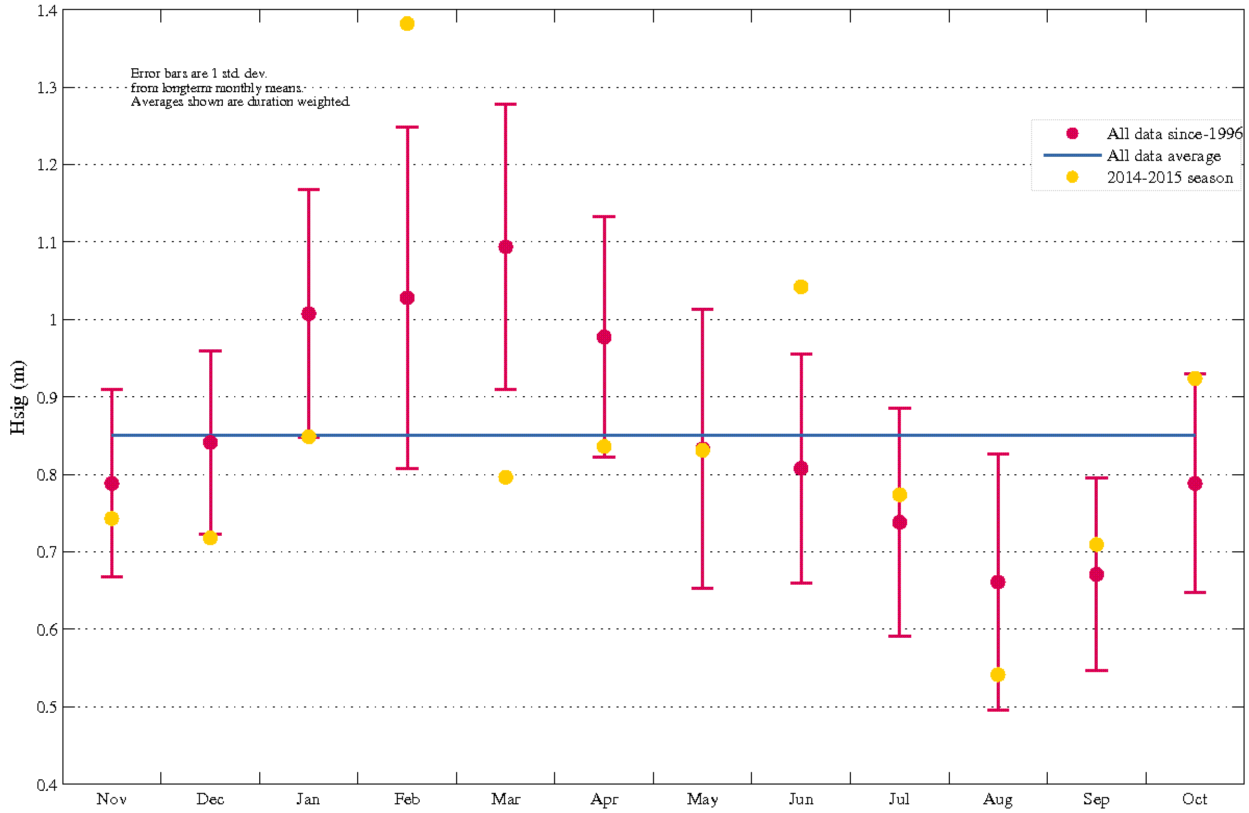


Figure 70 Emu Park – Monthly average wave height (Hsig) for seasonal year and for all data

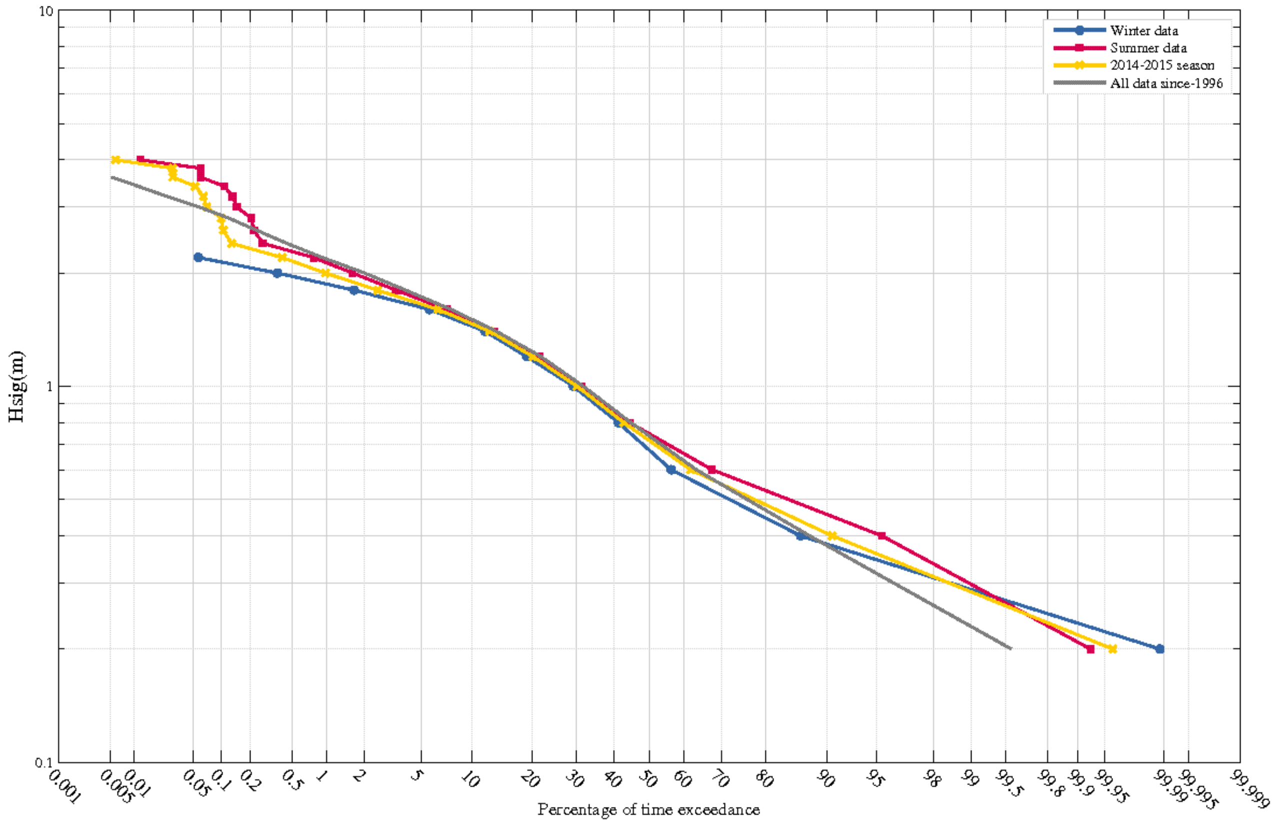


Figure 71 Emu Park – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

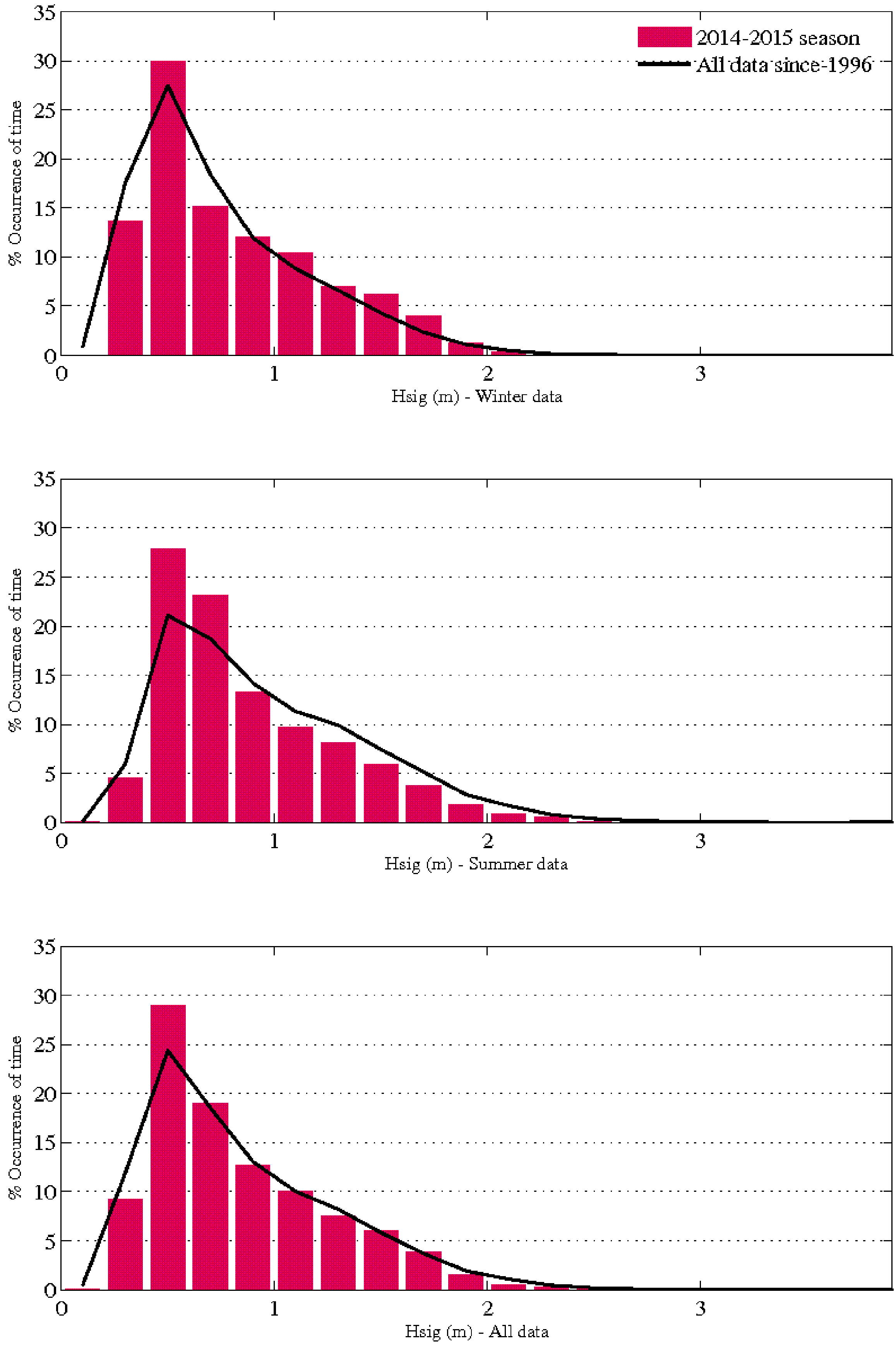


Figure 72 Emu Park – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

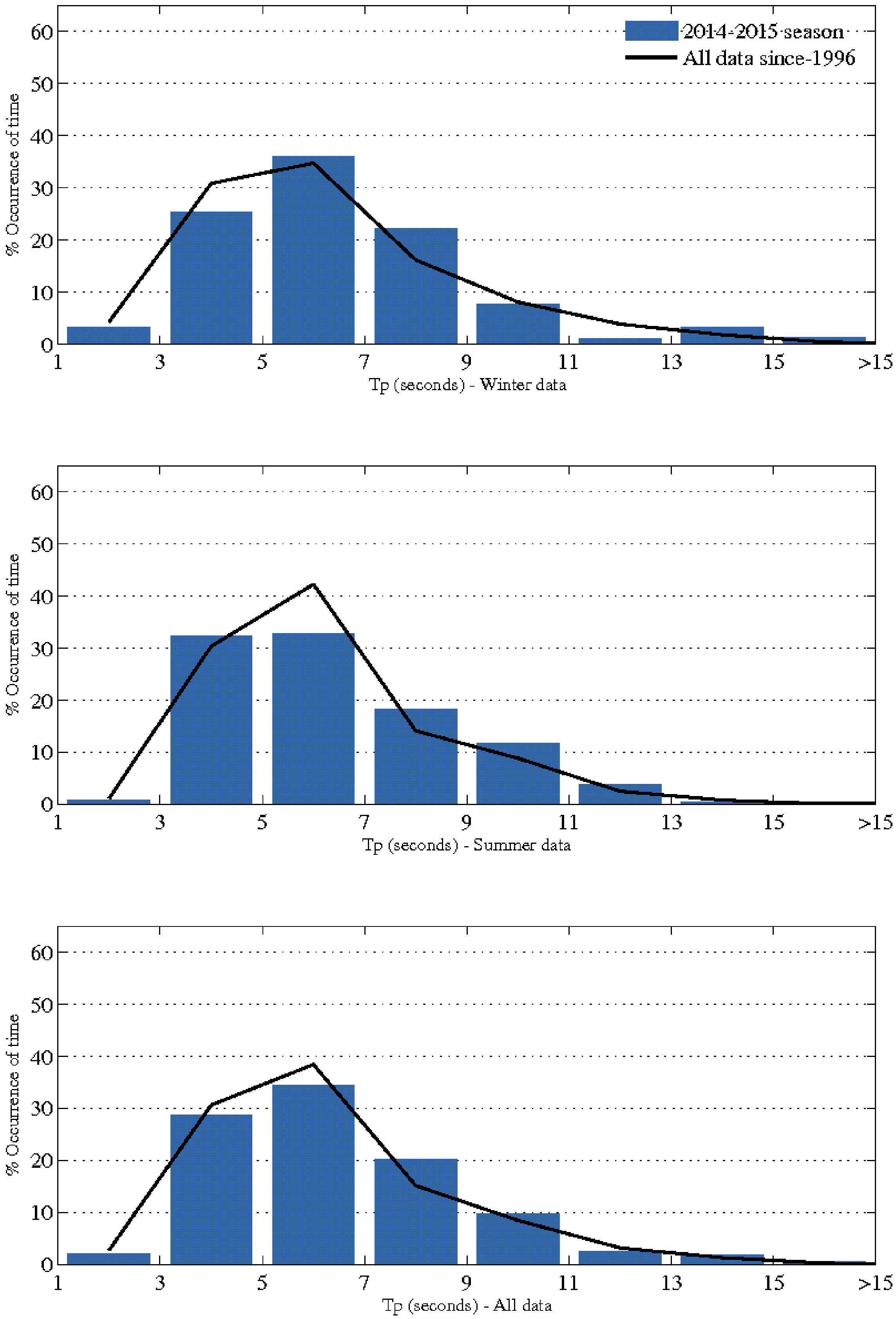


Figure 73 Emu Park – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

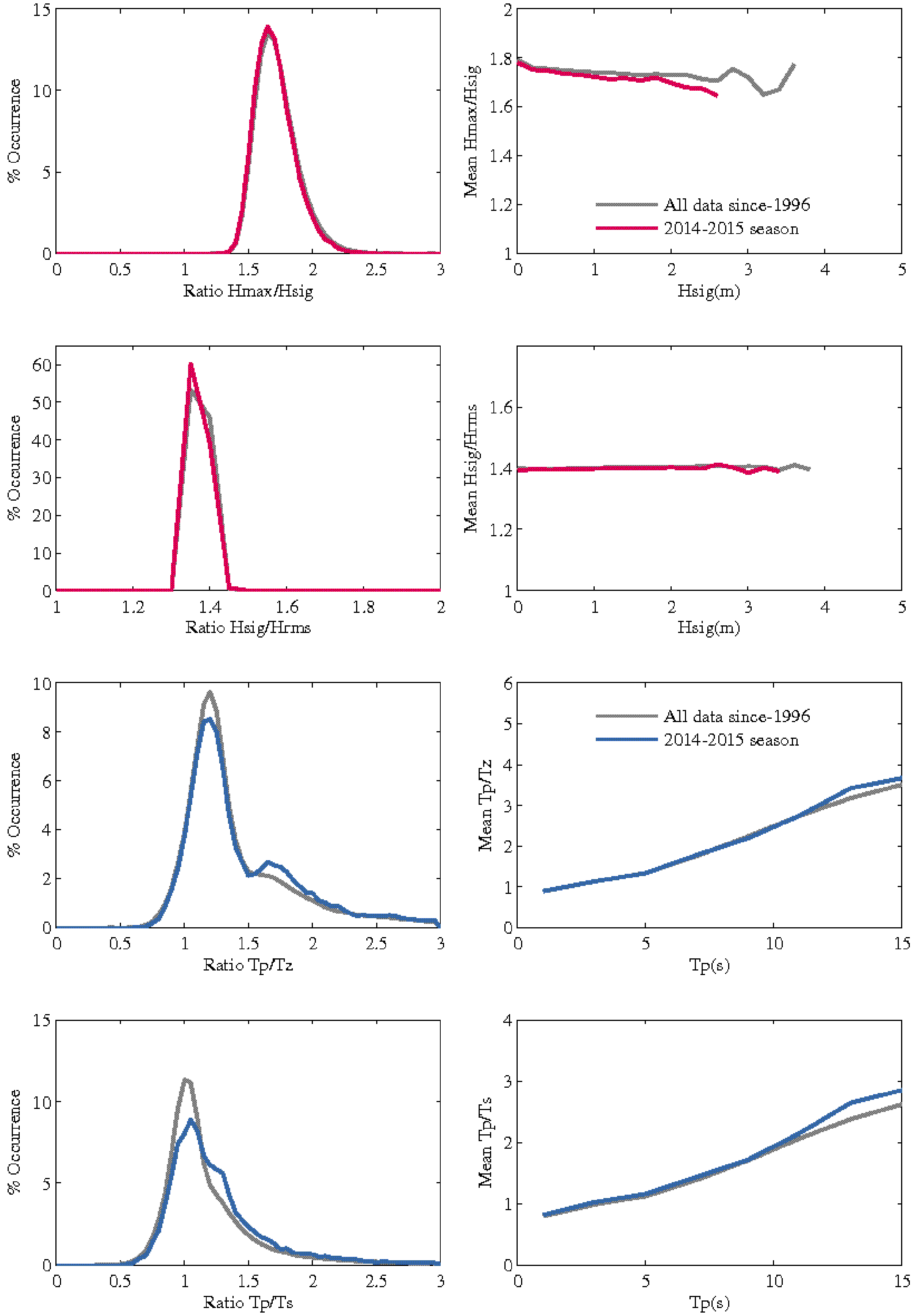
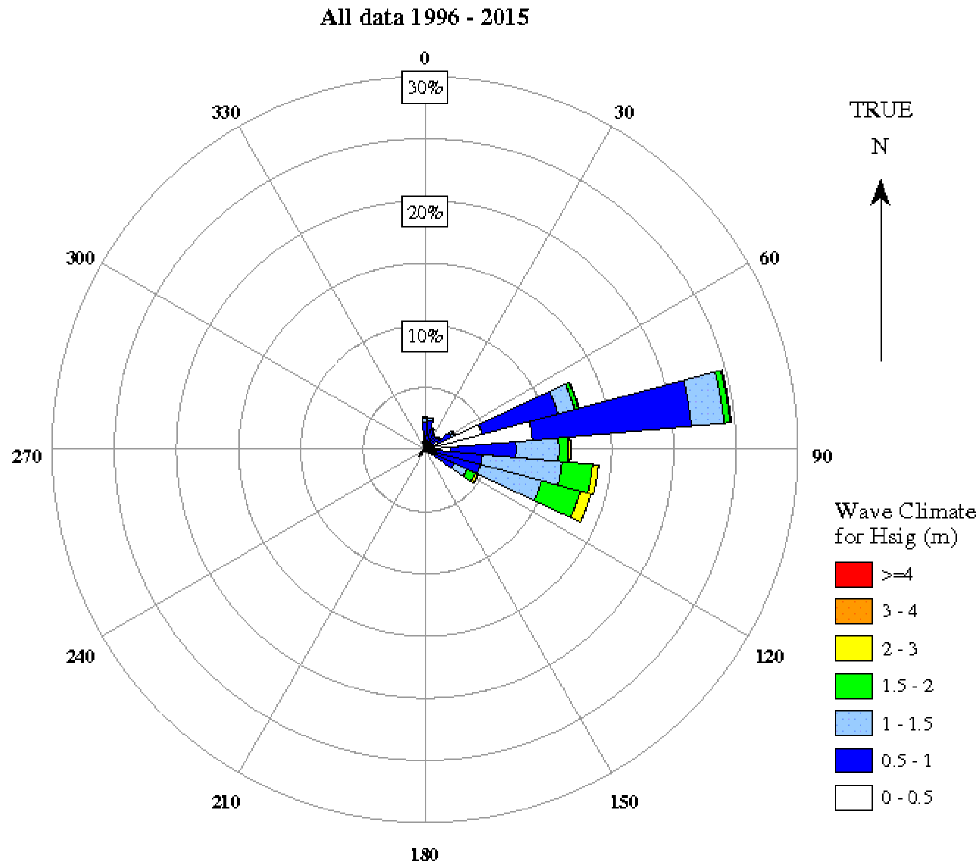


Figure 74 Emu Park – Wave parameter relationships



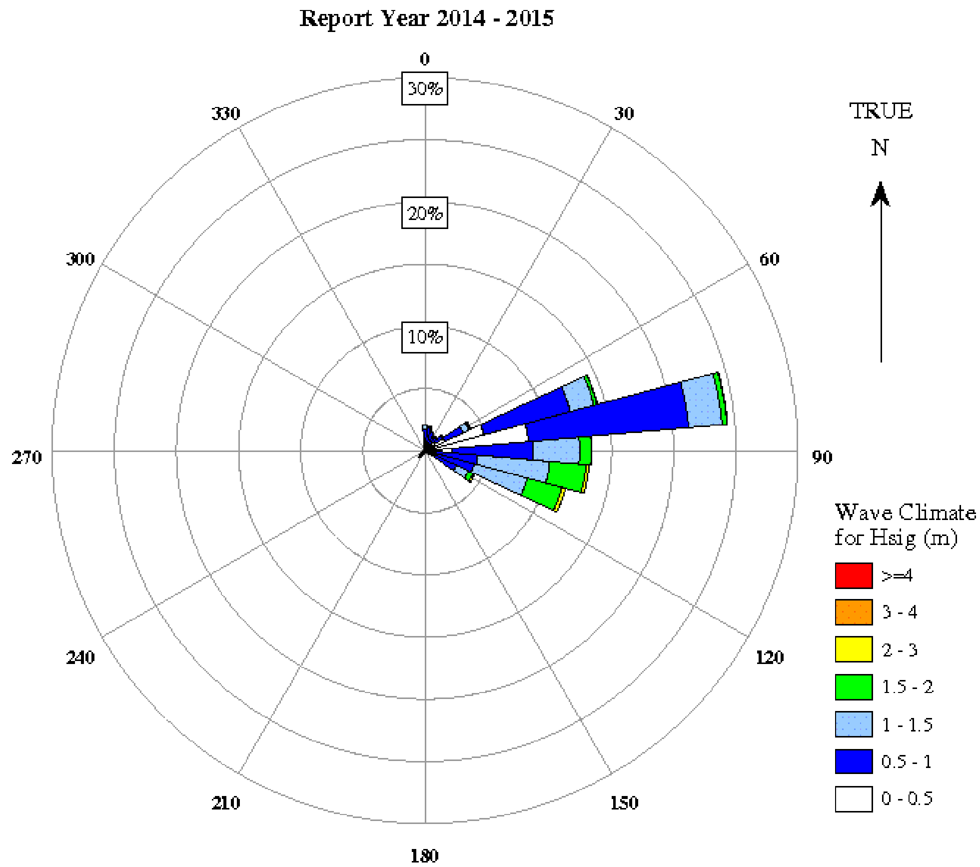


Figure 75 Emu Park – Directional wave rose

7.9 Hay Point

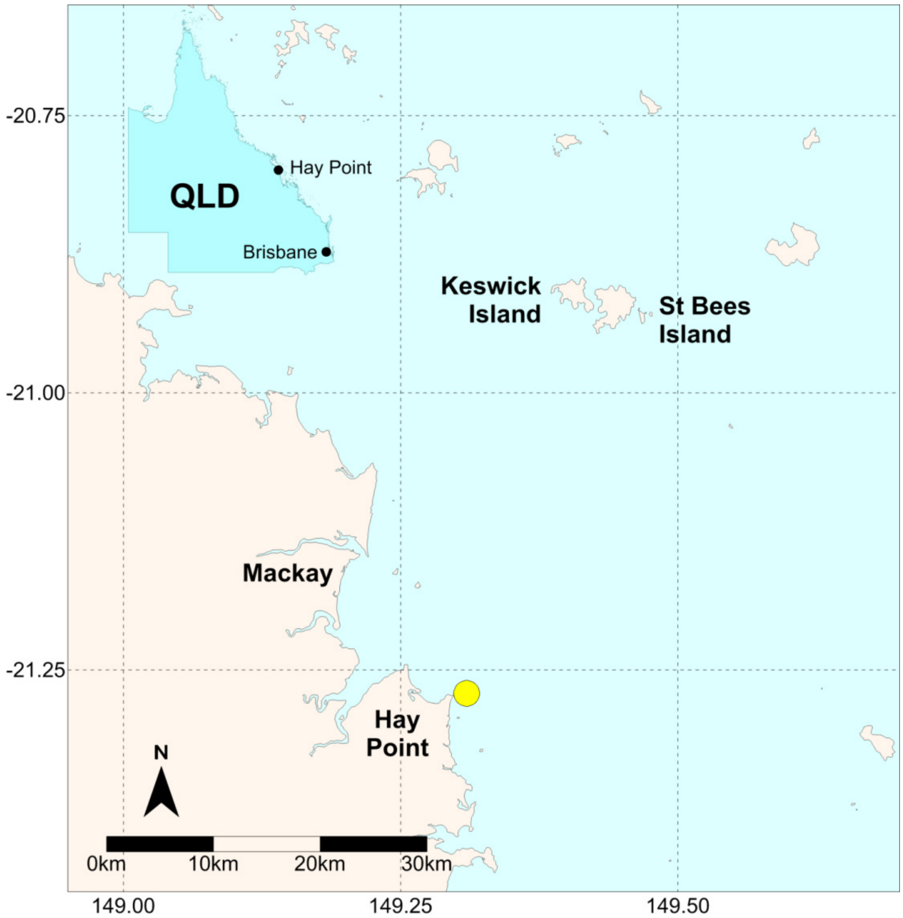


Figure 76 Hay Point – Locality plan

Table 37 Hay Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/04/1977	11.7 years	341,893	38.6
2014–15	01/11/2014	2.56 days	17,396	1

Table 38 Hay Point – Buoy deployments for the 2014–15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°16.270' S	149°18.586' E	10	23/03/2014	19/04/2015
21°16.332' S	149°18.696' E	13	19/04/2015	current

7.9.1 Hay Point – seasonal overview

The Hay Point wave buoy has been operational for just over 38.6 years. The data record for the period of November 2014 to October 2015 was excellent, with total gaps of 2.56 days, equivalent 99.3 per cent data return (Table 37). The buoy was replaced once during the reporting period on 19 April 2015 (Table 38).

The largest waves occurred during February of the reporting period during TC Marcia and TC Ola. The events weren't significant enough to exceed the top 10 highest waves (Table 40). The influence of TC Marcia and TC Ola (Table 41) can be seen by significant increases in wave height in the time series of daily wave recordings (Figure 77).

Peak wave direction (Figure 78) was predominately from the east, with occasional swings to the north and south. Sea surface temperature (SST) ranged from 18.5° C to 31° C (Figure 78) and was high enough for tropical cyclone development for the summer months and extended over the months February, March and mid April.

The monthly average Hsig generally didn't fell within one standard deviation (sd) of the long term mean. The months, which are situated above the +1sd, are July and October and the months, which are situated below the -1 sd, are November, December, January, March and August (Figure 79).

Percentage of time exceedance of Hsig (Figure 80) shows higher waves occurring through summer compared to winter. The overall wave climate during the reporting period was very similar to the wave climate of the whole record and this is also reflected in histograms of the occurrence of Hsig and peak wave period (Tp) (Figure 81 and Figure 82). The most common Tp was 3–5 seconds, with periods during winter and summer having the same 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. 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 5:30	2.4	03/03/2004 21:00	4.7

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
06/02/2015 21:30	2.1 (2.1)	3.7 (4.3)	6.4	Tropical Cyclone Ola passed into the Coral Sea.
19/02/2015 22:30	1.9 (2.1)	3.5 (4.5)	7.0	Tropical Cyclone Marcia passed inland of the coast as it declined from a category 3 to a category 1 tropical cyclone

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.

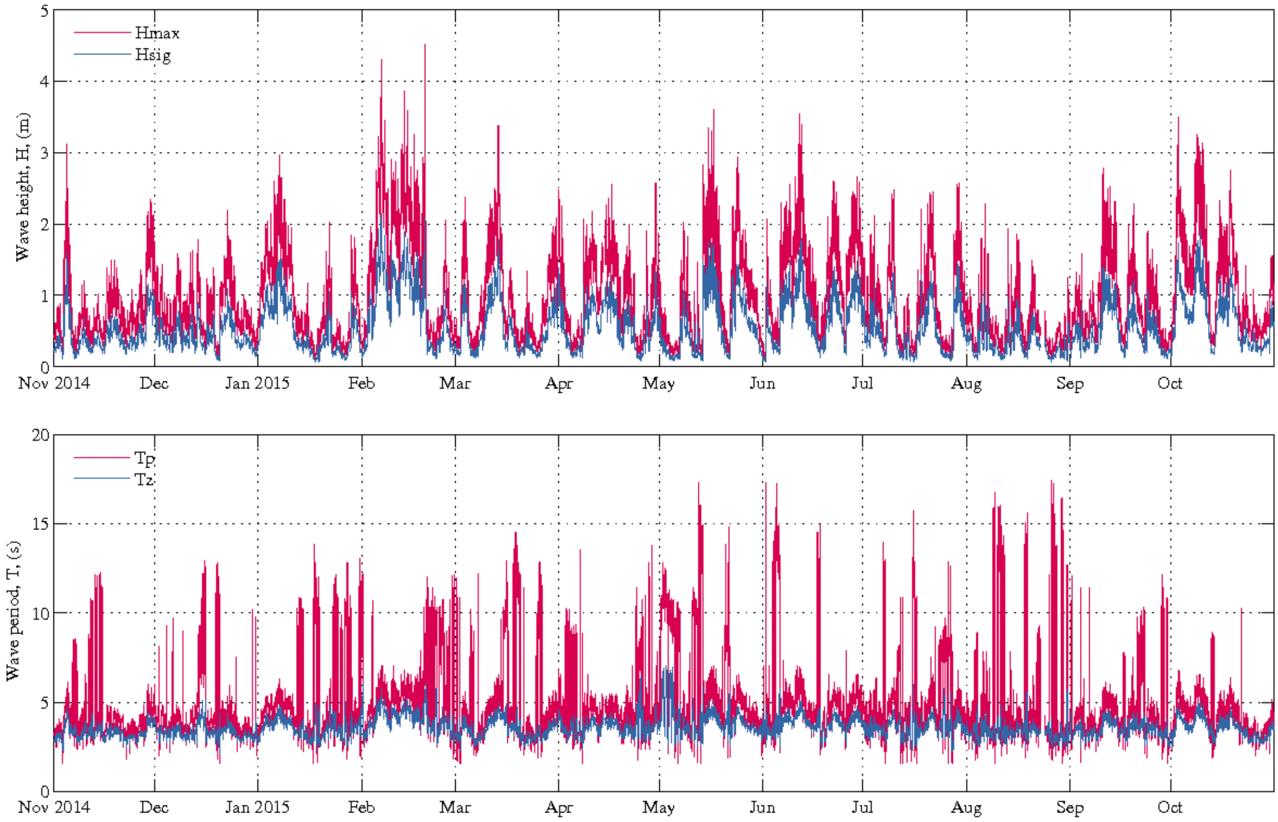


Figure 77 Hay Point – Daily wave recordings

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

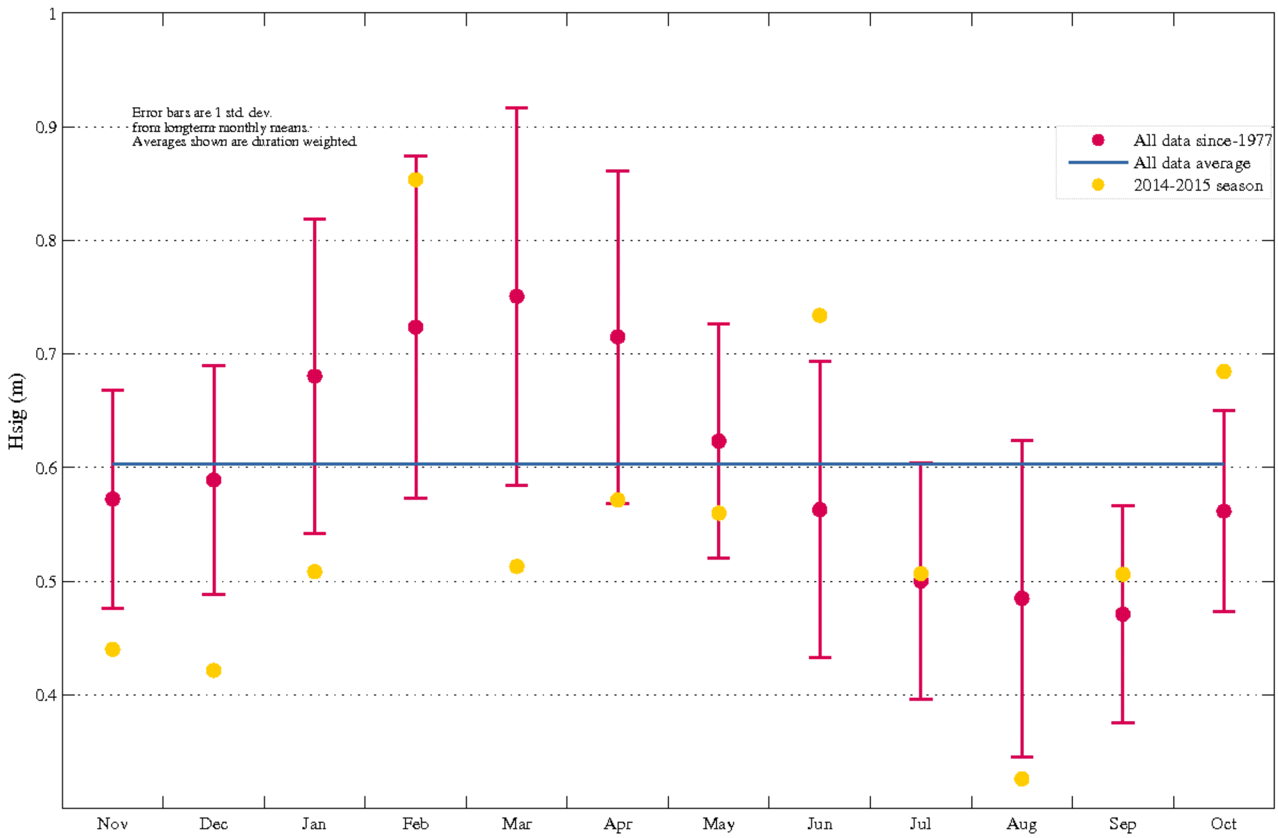


Figure 79 Hay Point – Monthly average wave height (Hsig) for seasonal year and for all data

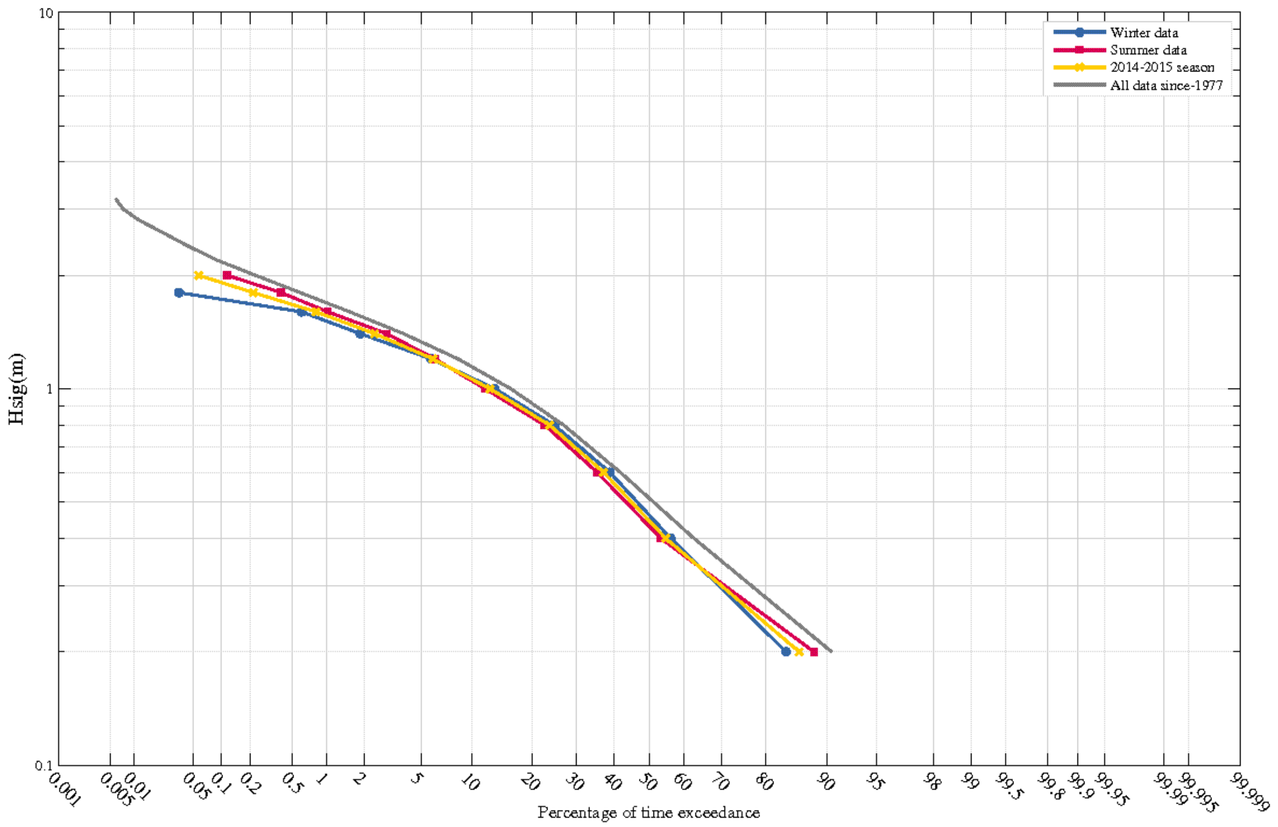
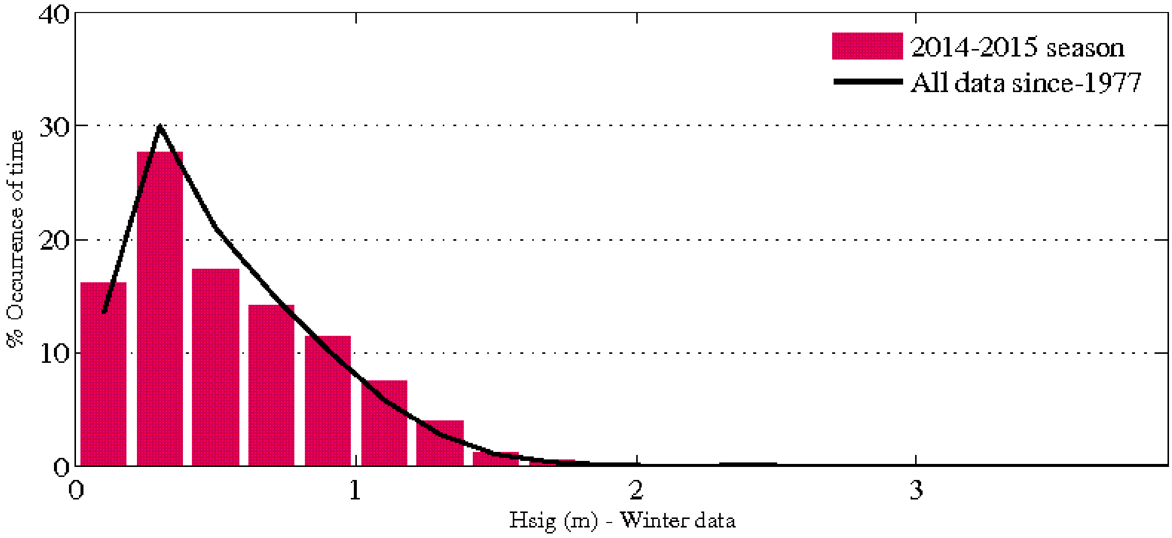
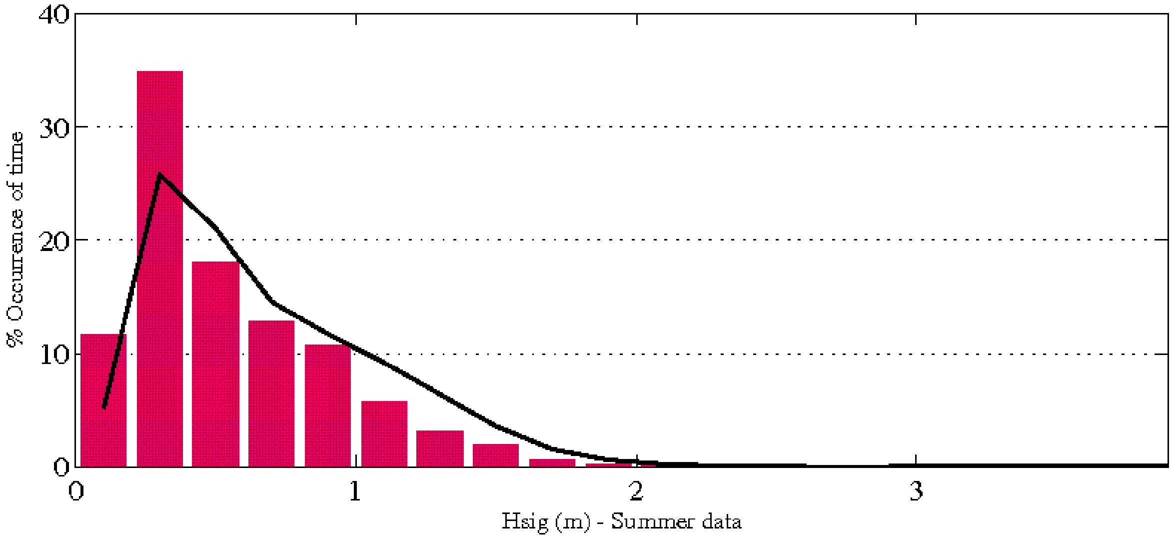


Figure 80 Hay Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)





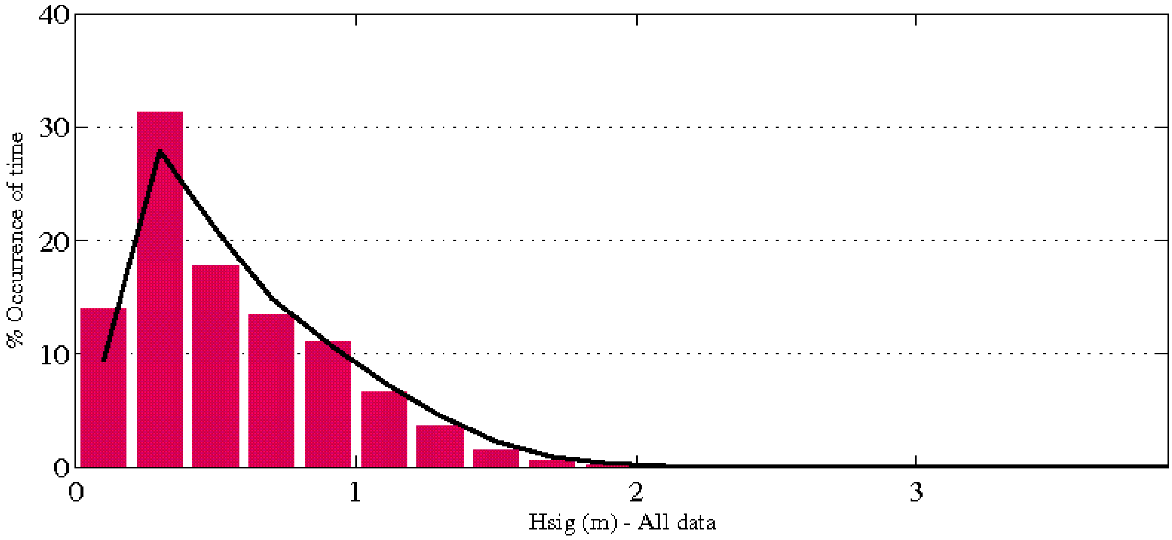
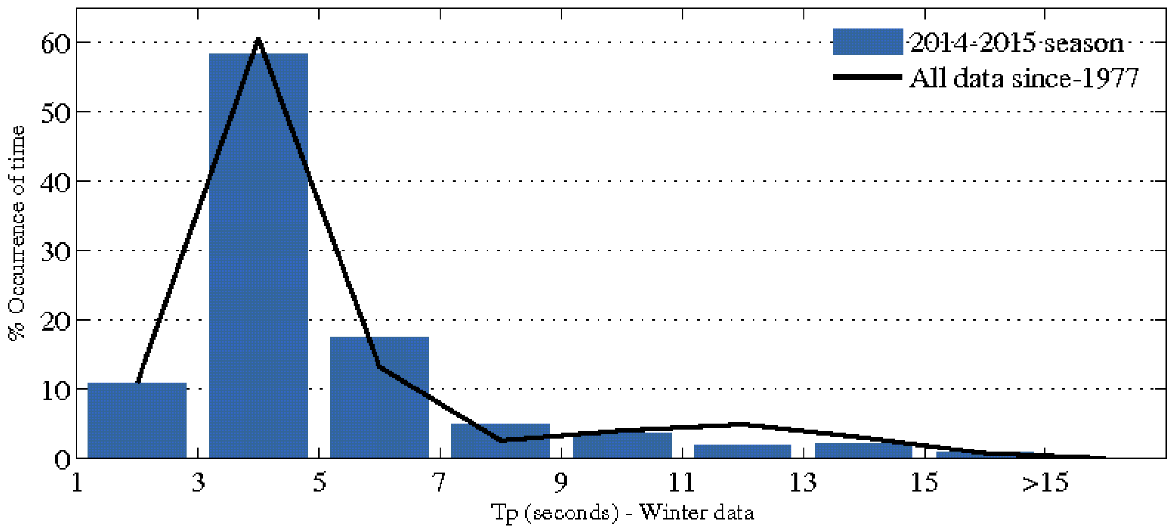
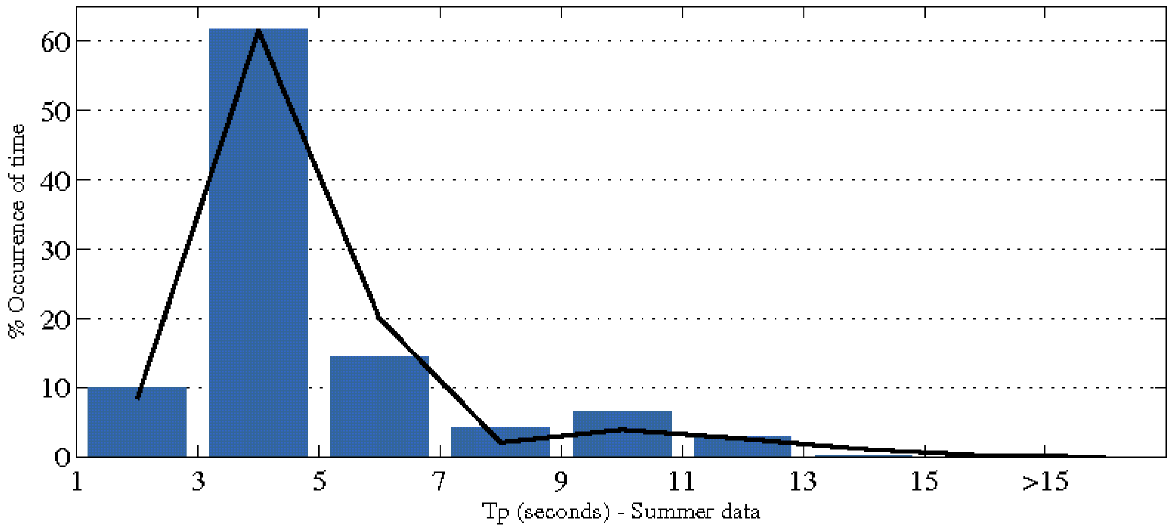


Figure 81 Hay Point – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)





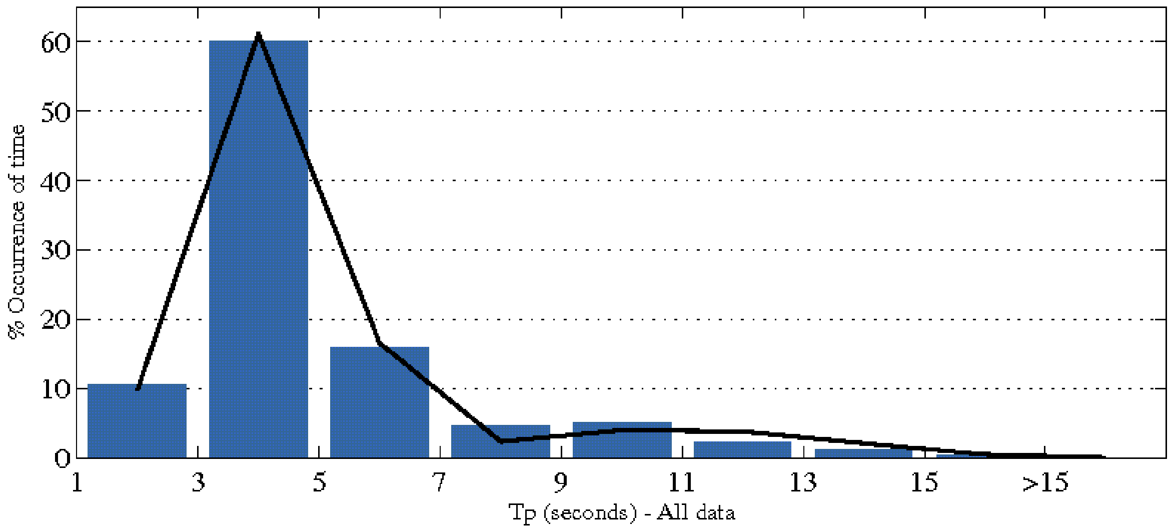


Figure 82 Hay Point – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

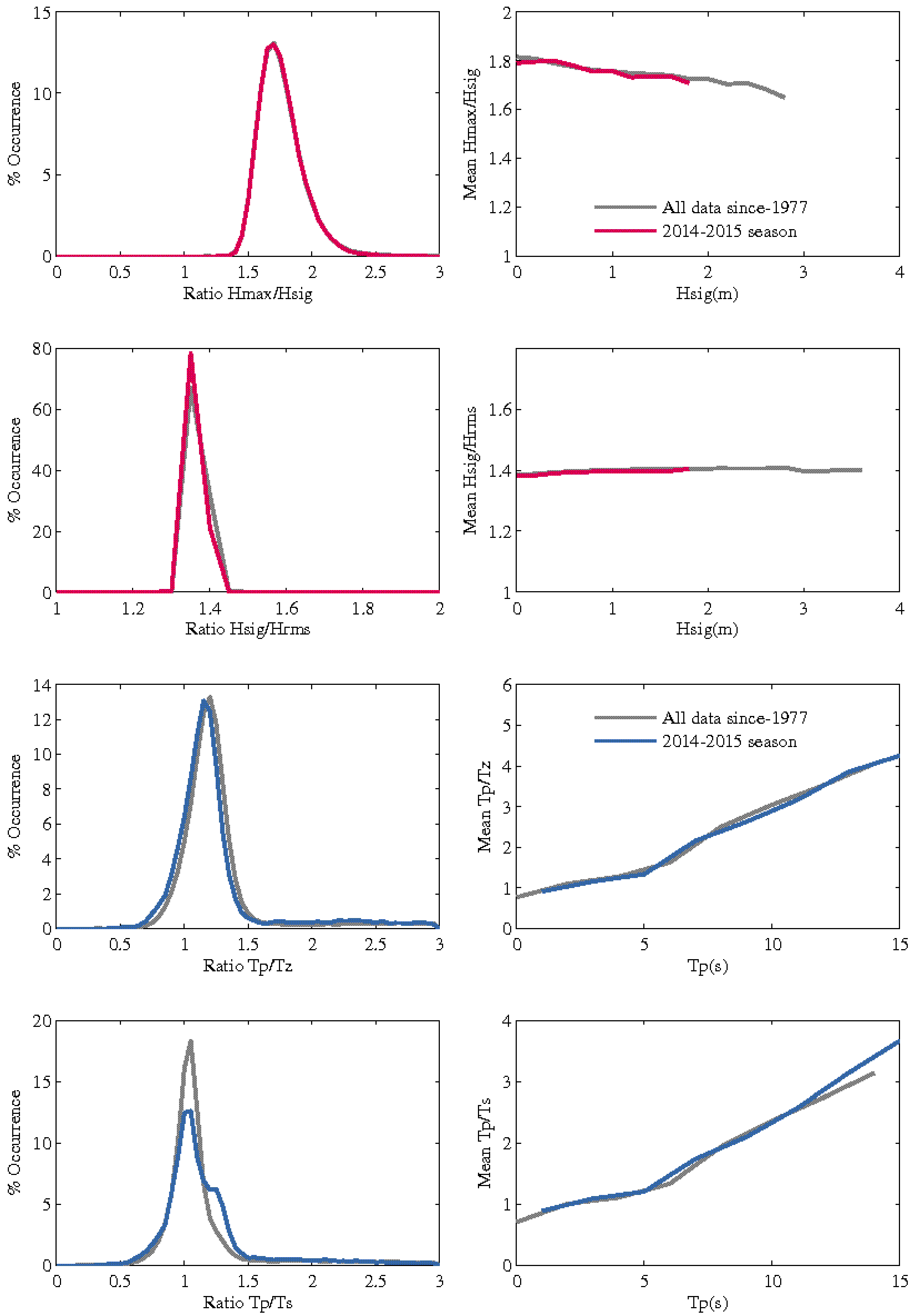
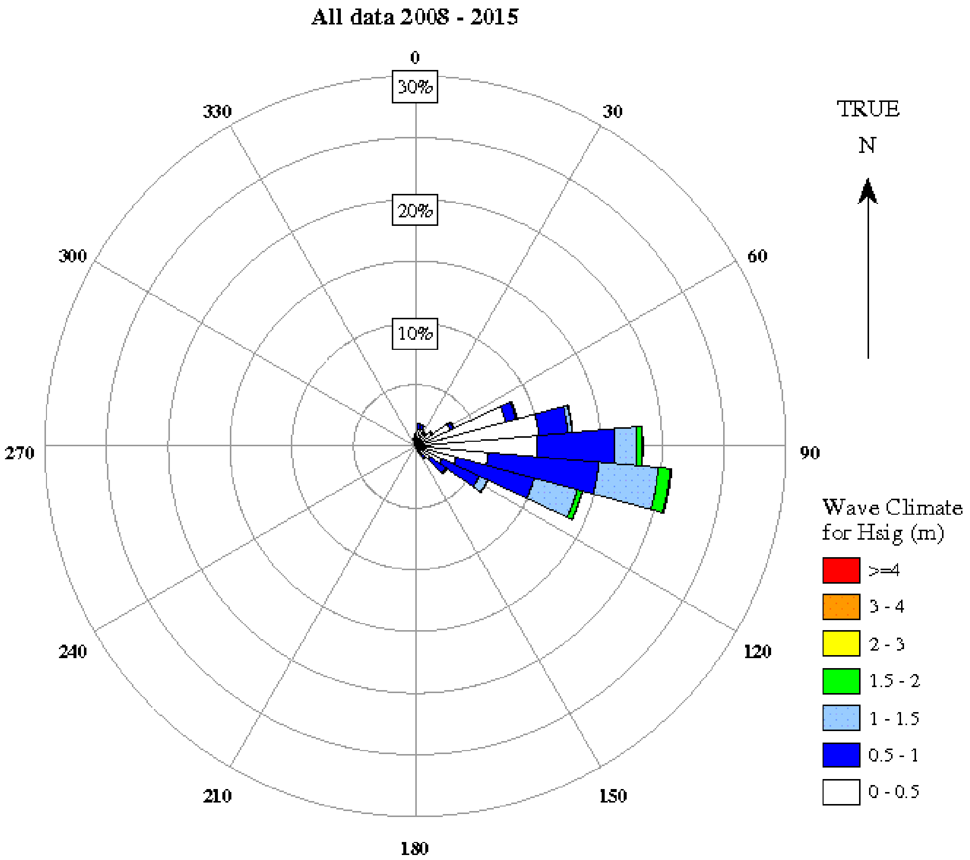


Figure 83 Hay Point – Wave parameter relationships



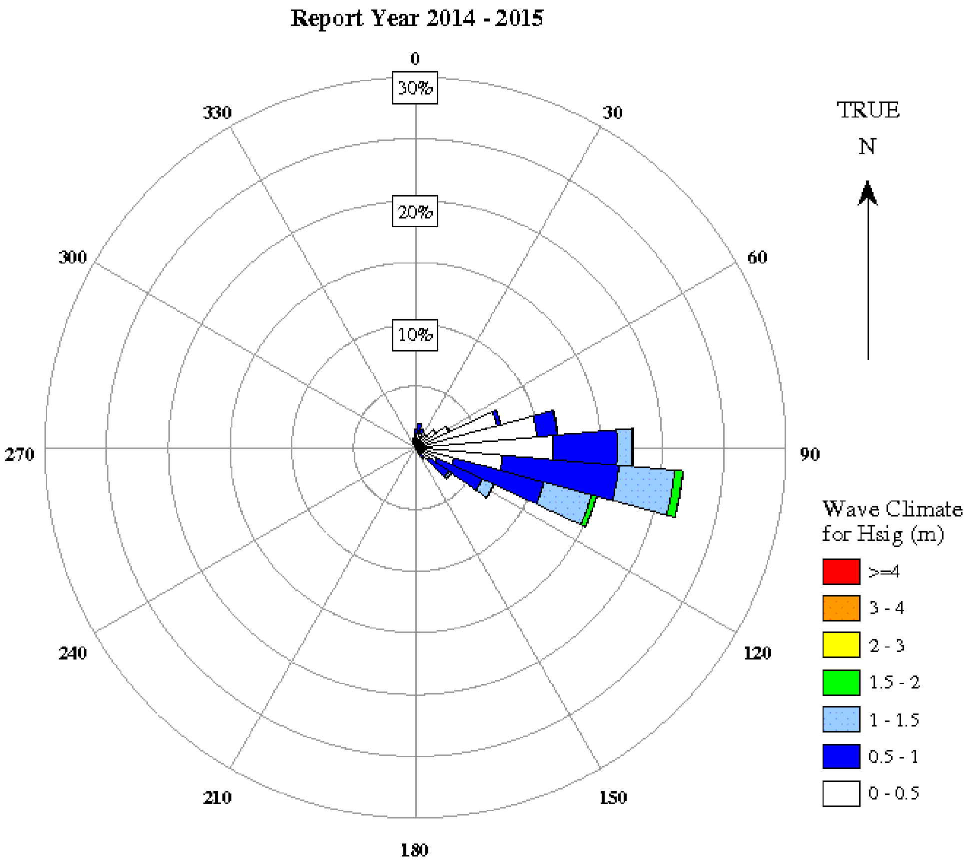


Figure 84 Hay Point – Directional wave rose

7.10 Mackay

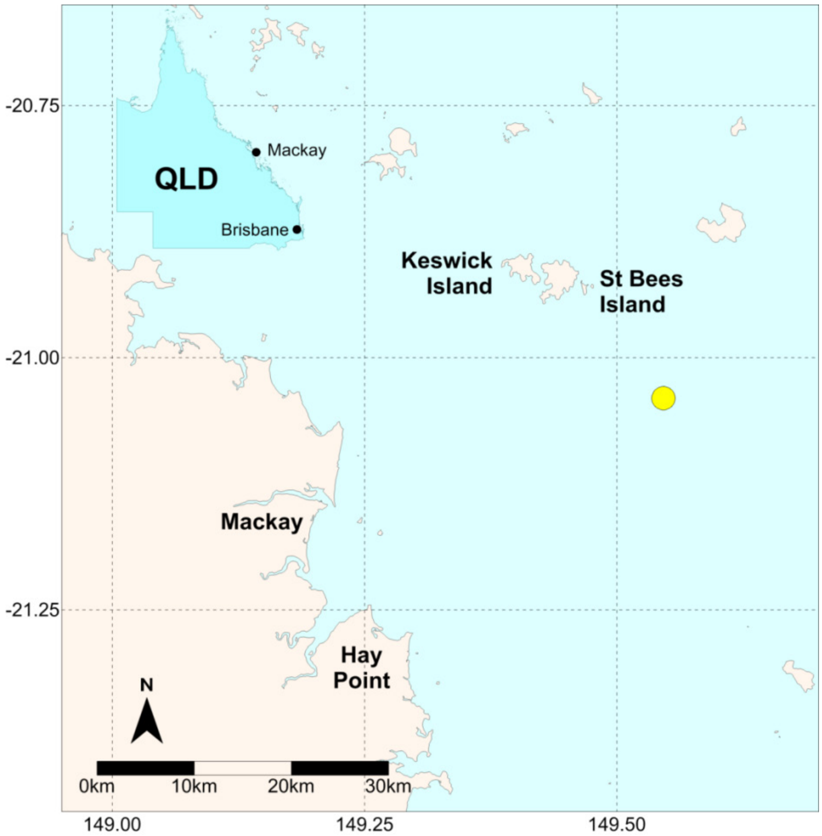


Figure 85 Mackay – Locality plan

Table 41 Mackay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	19/09/1975	13.4 years	296,909	40.1
2014–15	1/11/2014	68.7 days	14,224	1

Table 42: Mackay – Buoy deployments during the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°02.426' S	149°32.775' E	27.5	21/04/2014	17/06/2015
21°02.355' S	149°32.853' E	32	17/06/2015	current

7.10.1 Mackay – seasonal overview

The Mackay wave buoy has been operational for just over 40 years. The data recorded for the period from November 2014 to October 2015 was reasonable, with total gaps of 68.7 days, equivalent to 81.1 per cent data return. The overall data return is 66.6 per cent. The wave buoy was replaced on 17 June 2015 (Table 42).

In total three significant events happened during the reporting period. The events occurred in February and May, respectively TC Marcia and TC Ola (Table 44). The largest maximum waves during the reporting period occurred on 06 February as a result of TC Ola passing into the Coral Sea and is ranked number 7 (Table 43), with a height of 7.3 metres. During the TC Marcia, waves with a Hsig of 3.6 are recorded and ranked 7 of the highest Hsig. 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). The Sea surface temperature (SST) ranged from 18.5° C to 31° C (Figure 87). The SST was high enough for tropical cyclone development for the summer months and extended over the months November, February, March and until mid April.

Monthly average Hsig (Figure 88) exceeded one standard deviation (sd) in January and August of the recording period. January experienced much higher waves than past records and subsequently exceeding +1 sd significantly. November was also on the bounds of exceeding -1 standard deviation.

Percentage exceedance of Hsig (Figure 89) shows a very similar wave climate between the reporting period and the entire record. Overall the waves has been slightly lower than for the entire record. Histograms for percentage occurrence of Hsig (Figure 90) and peak weave period (Tp) (Figure 91) also show similar distributions between the recent reporting period and the entire record. The Hsig 0.4 m–0.6m has a higher percentage of occurrence for both the summer and winter months. Noteworthy, are the >1 m waves during the winter months, they occurred less compared to the entire 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 92). The ratio Tp/Ts has 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. This is 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 3:41	3.9	19/01/2004 19:30	7.5
6	05/06/2002 0:00	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 3:00	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
06/02/2015 21:00	3.2 (3.2)	7.2 (7.3)	7.9	Ex - Tropical Cyclone Ola passed into the Coral Sea.
19/02/2015 22:30	3.5 (3.6)	5.5 (5.9)	8.2	Tropical Cyclone Marcia made landfall just north of Yepoon.
14/05/2015 6:30	2.7 (3.3)	4.8 (6.2)	6.8	A vigorous cold front crossed southeast Australia ahead of a strengthening high pressure system, with southerly flow persisting across much of southeast 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.

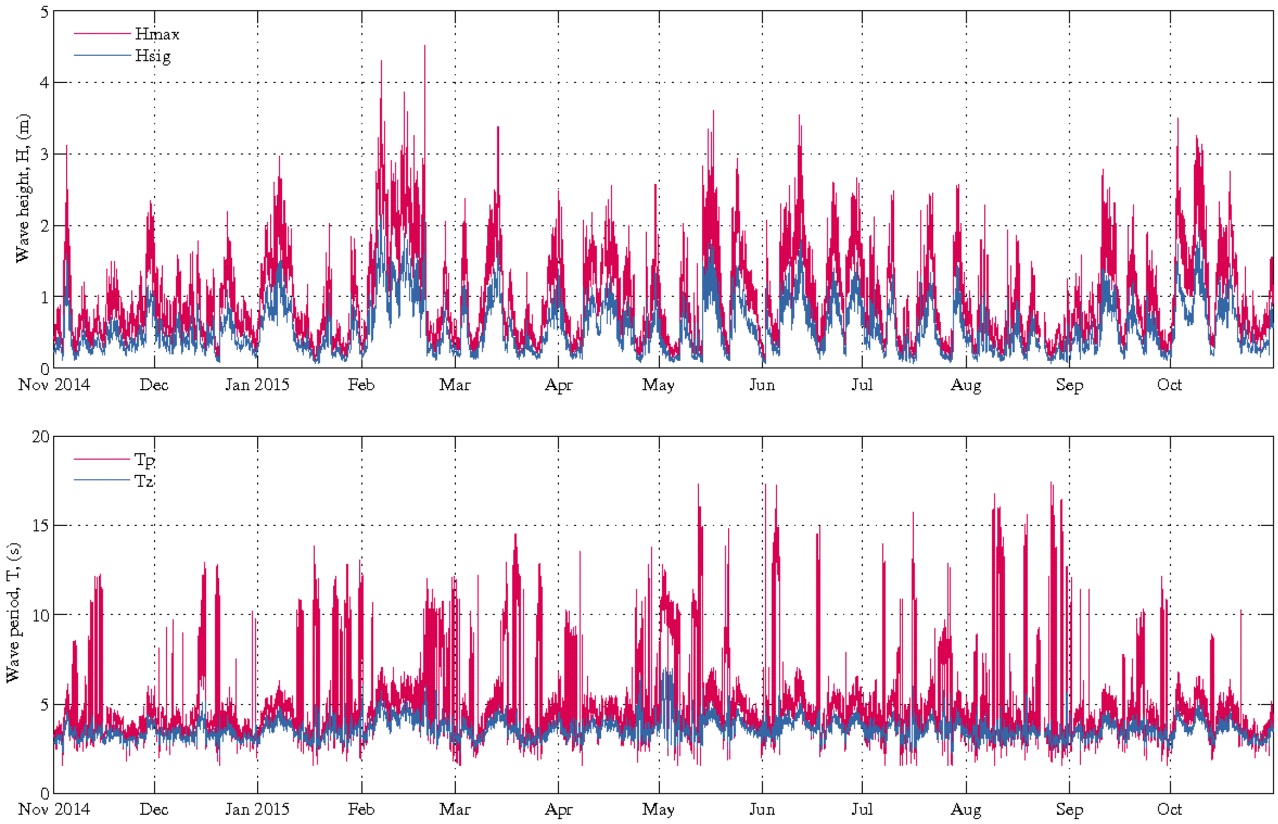


Figure 86 Mackay – Daily wave recordings

Figure 87 Mackay – Sea surface temperature and peak wave directions

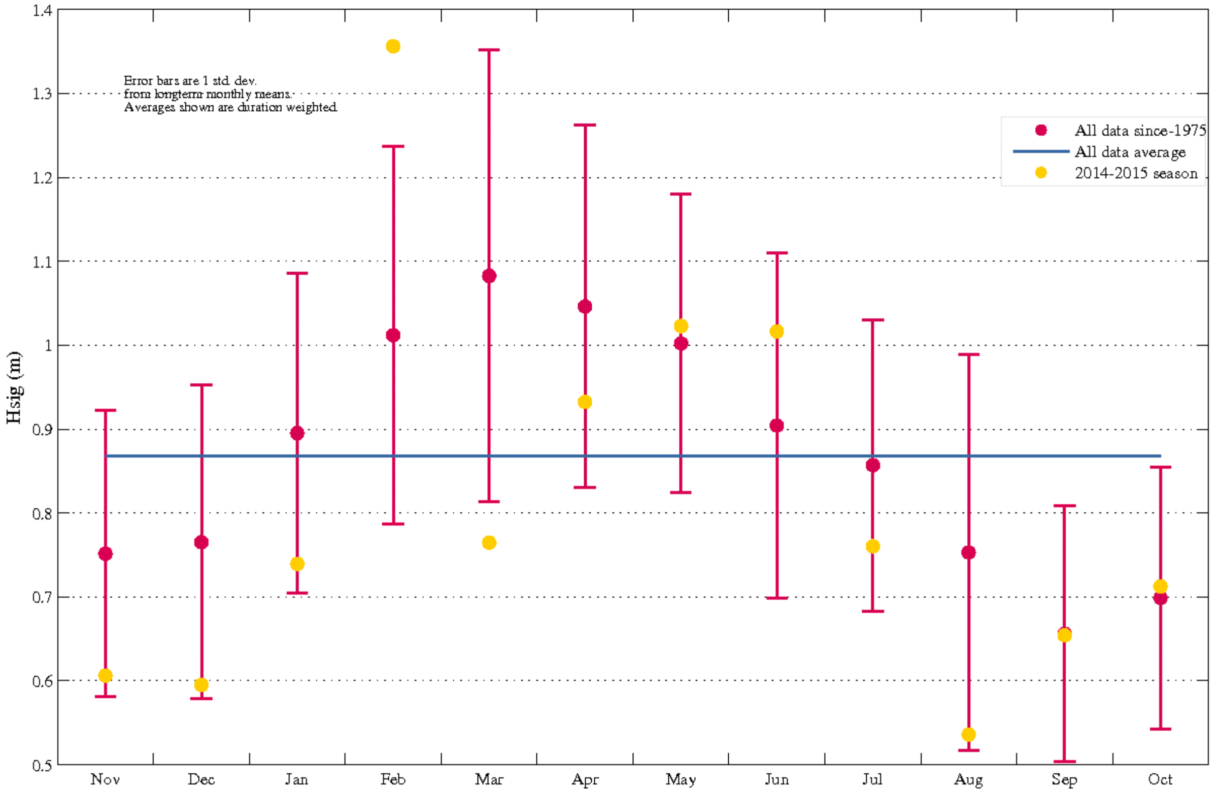


Figure 88 Mackay – Monthly average wave height (Hsig) for seasonal year and for all data

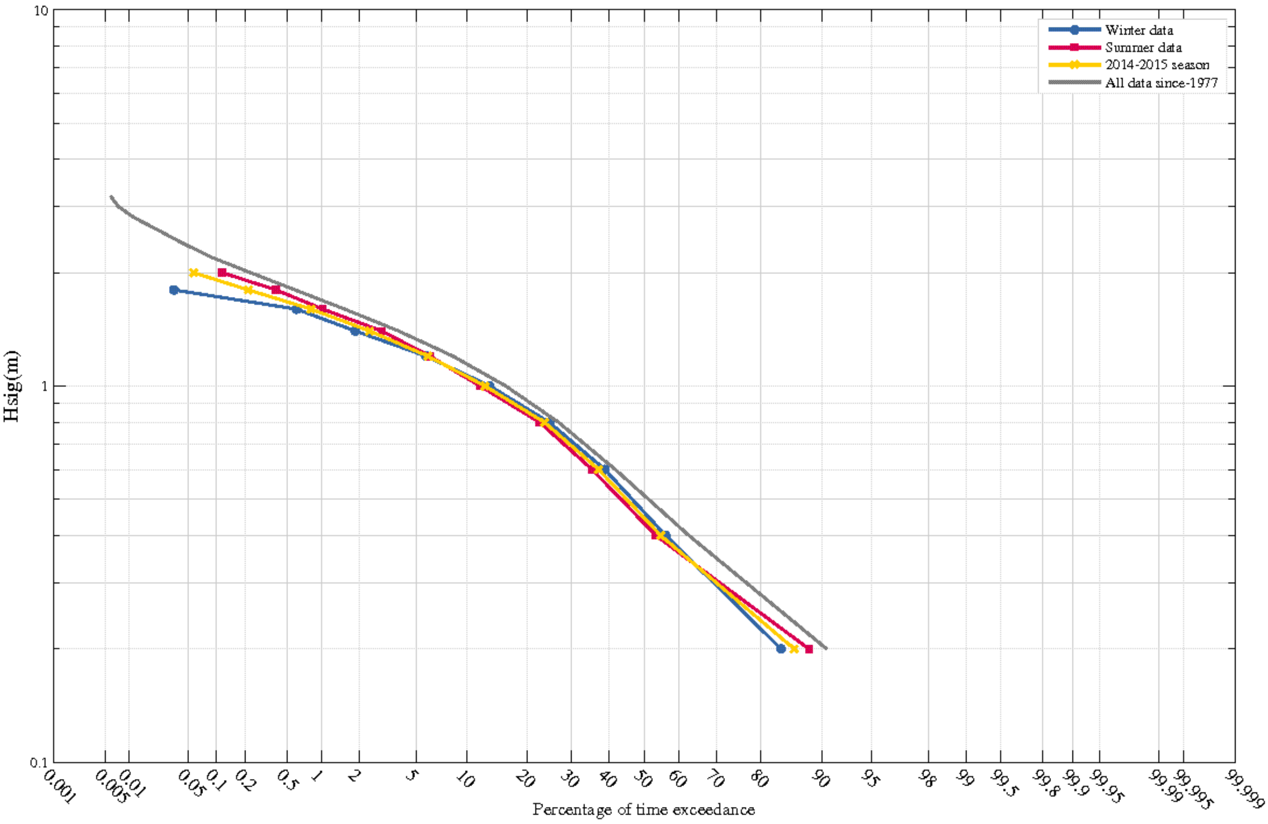
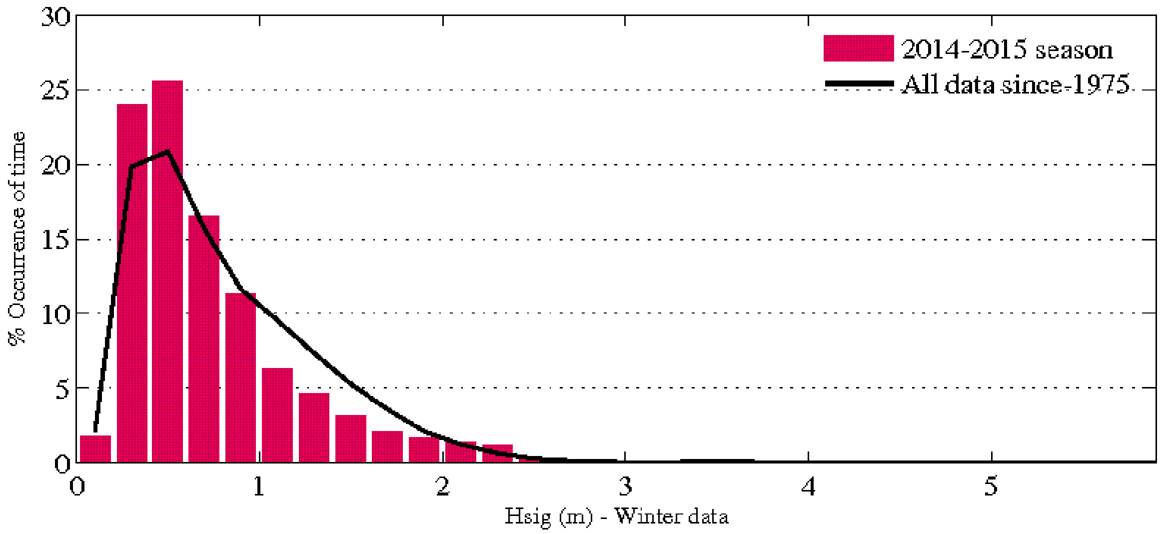
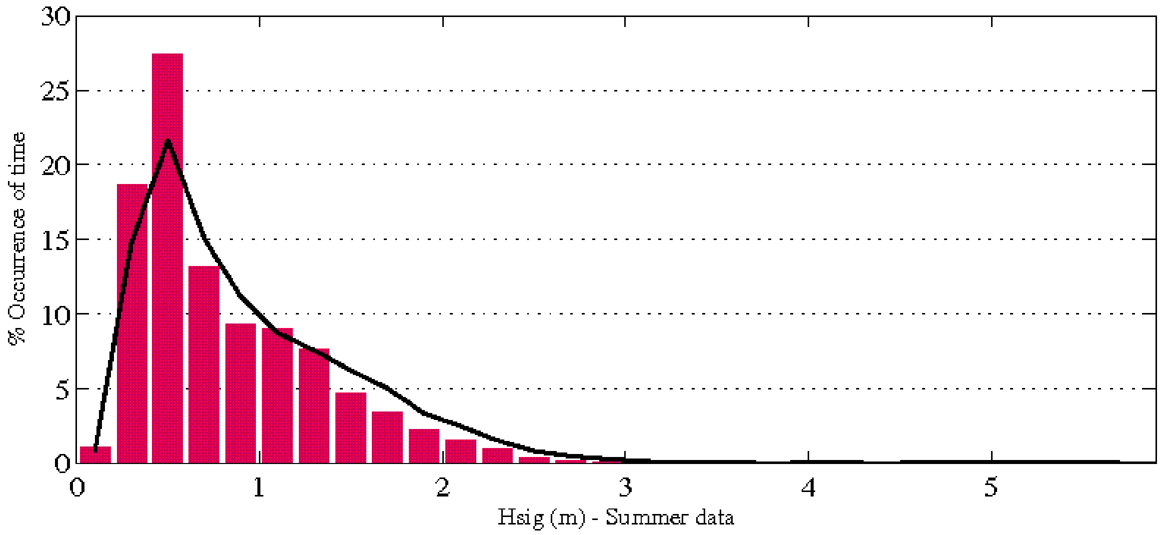


Figure 89 Mackay – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)





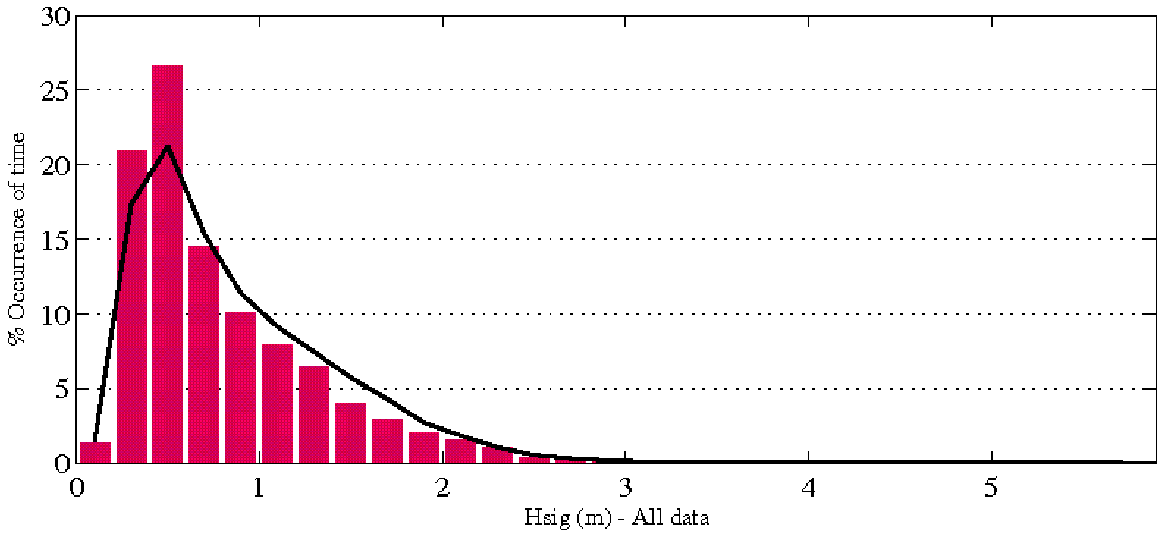


Figure 90 Mackay – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

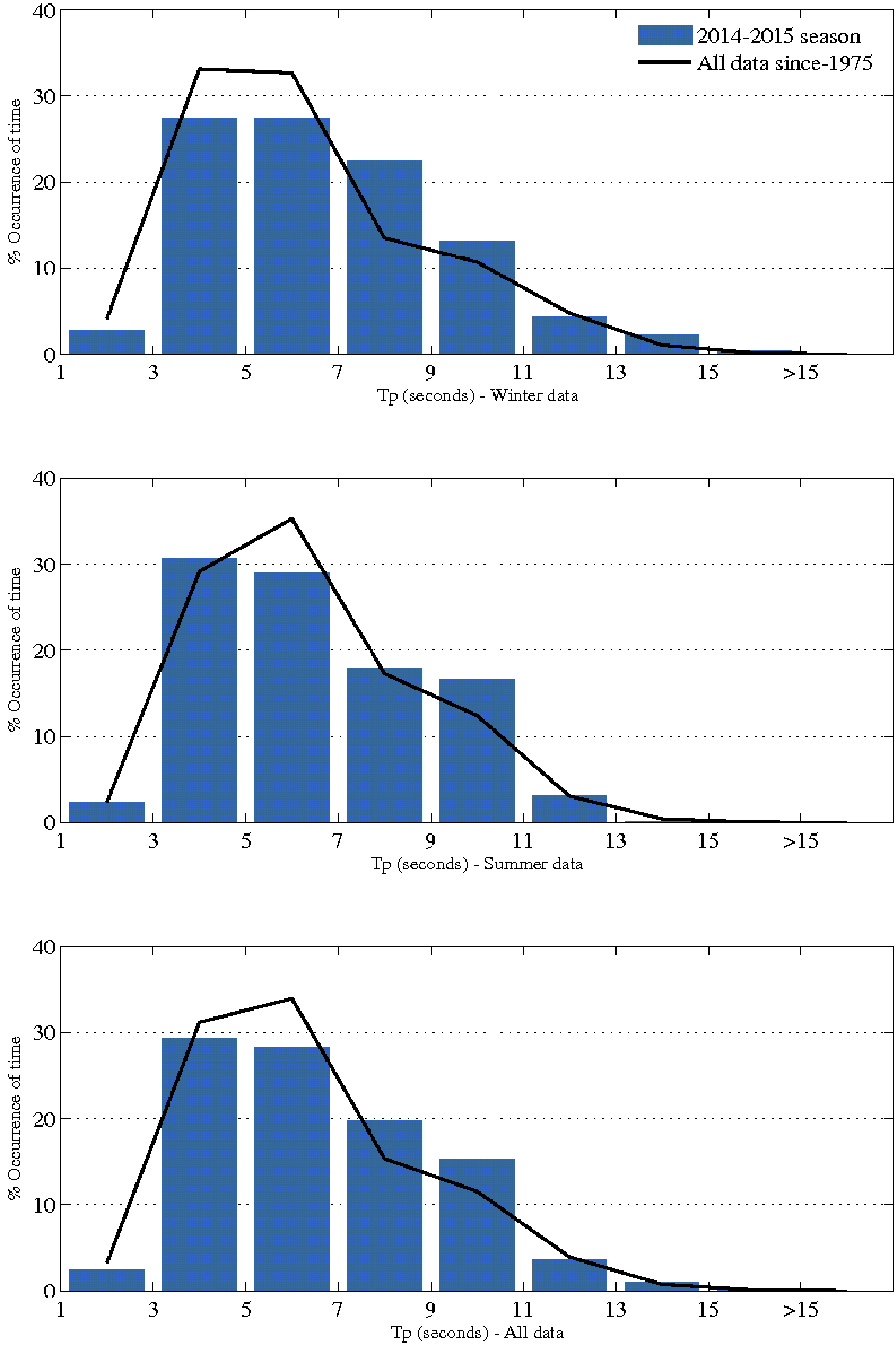


Figure 91 Mackay – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

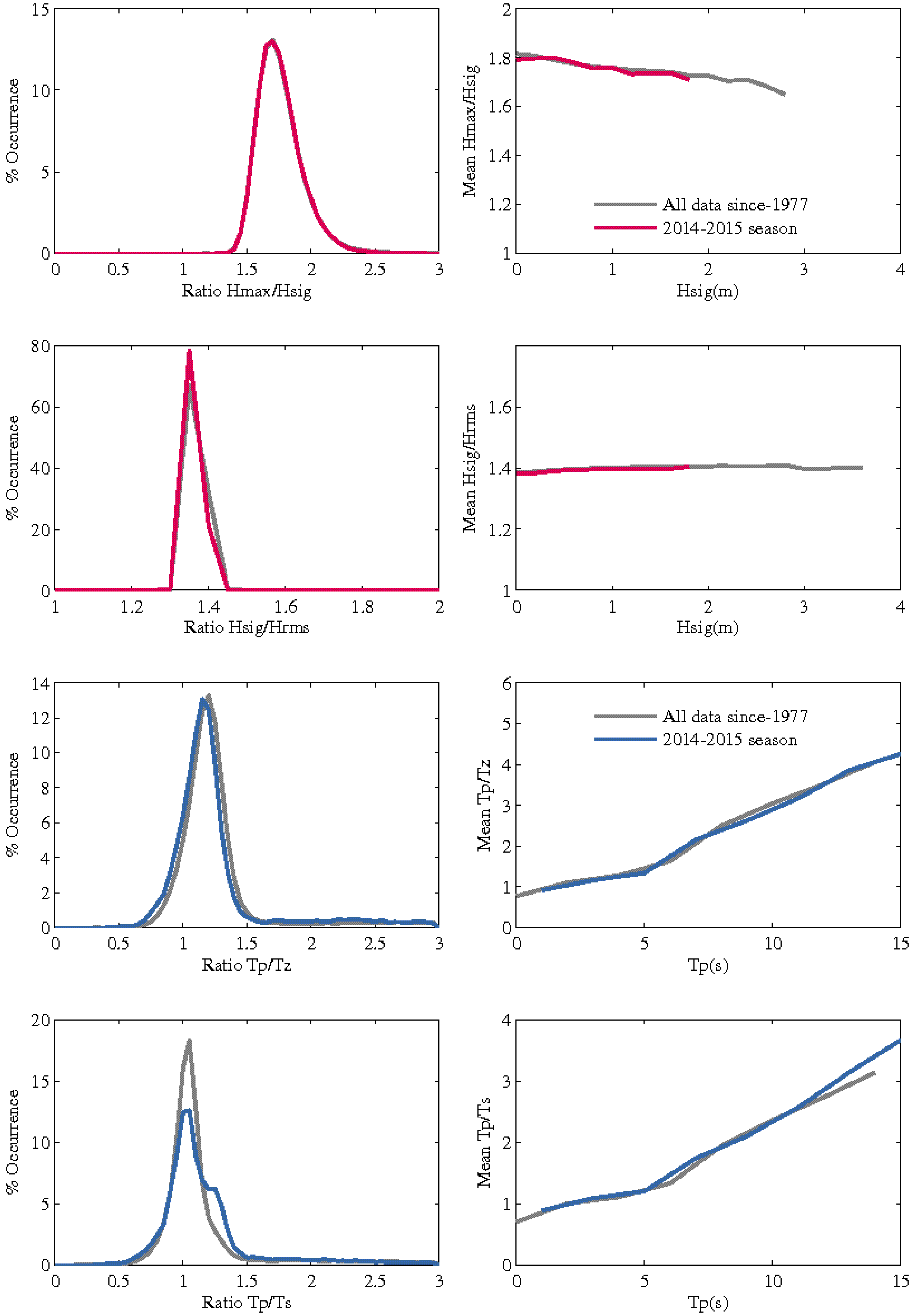
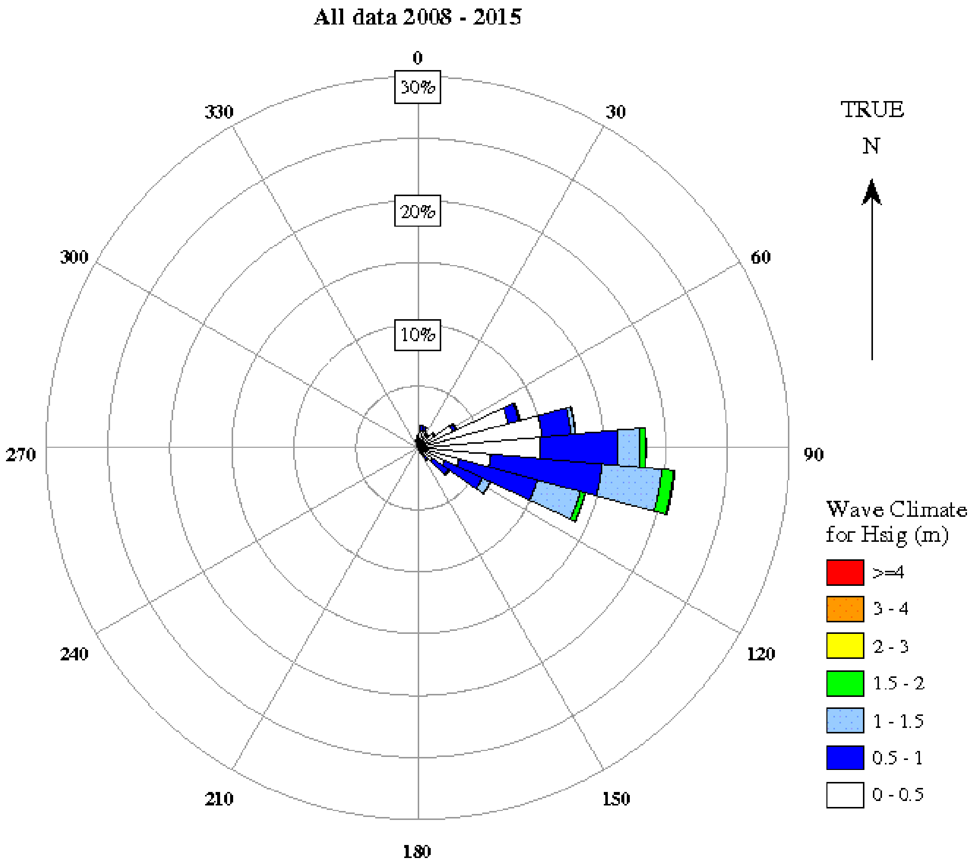


Figure 92 Mackay – Wave parameter relationships



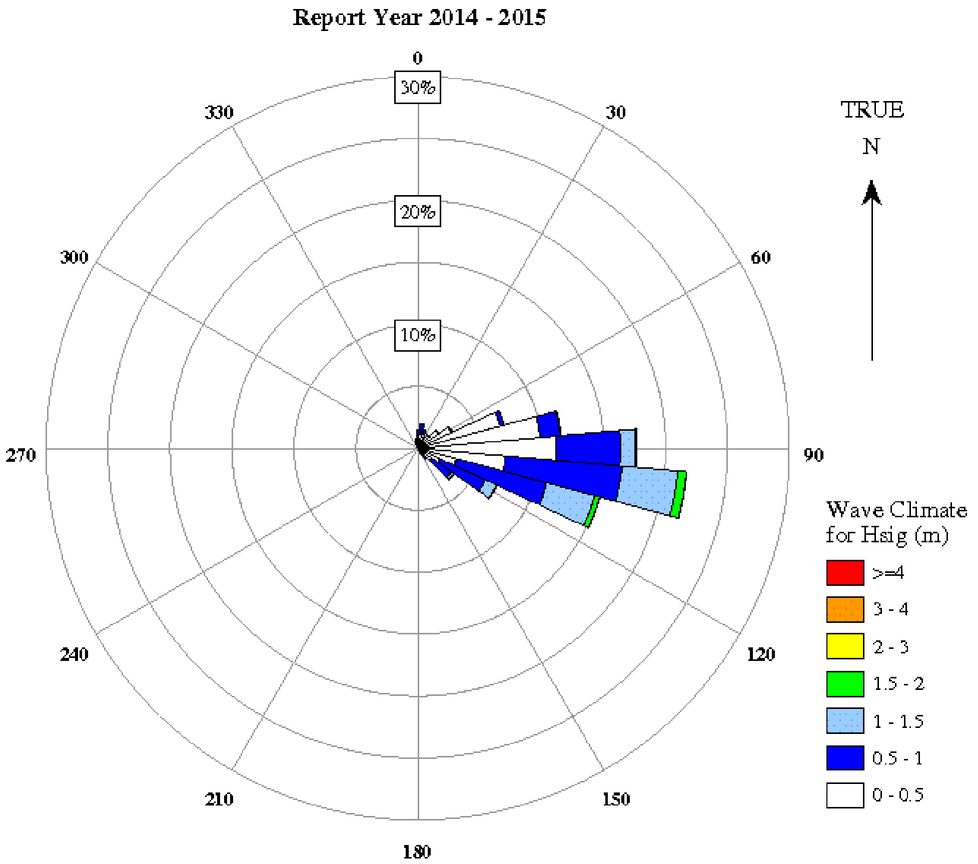


Figure 93 Mackay – Directional wave rose

7.11 Abbot Point

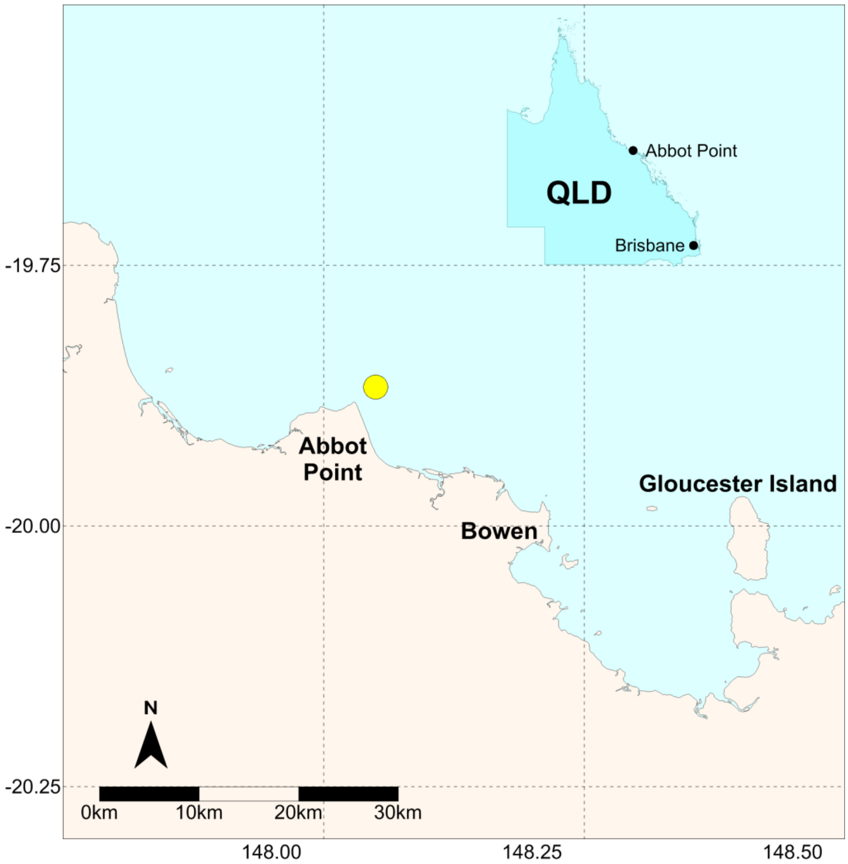


Figure 94 Abbot Point – Locality plan

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	65,230	3.8
2014–15	01/11/2014	0.94 days	17,474	1

Table 46 Abbot Point – Buoy deployment for the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
19°51.975' S	148°05.845' E	14	05/02/2014	24/01/2015
19°51.956' S	148°05.883' E	14	24/01/2015	current

7.11.1 Abbot Point – seasonal overview

The Abbot Point wave buoy has only been operational for just under four years. The data recorded for the period from November 2014 to October 2015 was excellent, with total gaps of 0.94 days, equivalent to 99.7 per cent data return (Table 45). The overall data return is 98.4 per cent. The wave buoy was replaced on 24 January (Table 46).

The Abbot Point buoy has only been operational for a short time. Comparisons have been made in this report between previous recordings and recordings made in this reporting period for the first time.

The largest waves recorded by the Abbot Point wave rider buoy during the reporting period occurred in October as a north westerly airstream being directed into the southeast of the continent. This generated a significant wave height (Hsig) of 1.6 m, ranked 7 (Table 47), on 03 October.

Peak wave direction (Figure 96) was predominately from east-north-east. Sea Surface Temperature (SST) values ranged from 20.5° C to 31° C (Figure 96) were the SST was high enough for tropical cyclone development for the summer months with the exception of periods during November, March, April and May.

The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean. The months which are situated above the +1sd, are February, June, September and October and the months which are situated below the -1 sd, are December and May (Figure 97).

Percentage exceedance of Hsig (Figure 98) and the histogram of percentage occurrence of Hsig (Figure 99) show to have similar wave heights during summer and winter. The most common Tp was between 3 to 5 seconds in both summer and winter (Figure 99).

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	21/03/20120 3:00	1.9	12/04/2013 00:00	3.6
4	12/04/2013 00:00	1.8	20/03/2012 23:00	3.4
5	02/02/20120 7:00	1.7	15/01/2014 10:30	3.4
6	12/04/2012 15:00	1.6	11/07/2012 04:00	3.3
7	03/10/2015 15:00	1.6	12/04/2012 15:00	3.3

8	09/03/2014 15:00	1.6	01/12/2013 22:30	3.2
9	11/07/2012 03:00	1.5	02/02/2012 07:00	3.2
10	6/09/2013 11:00	1.5	19/12/2013 13:30	3.0

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
03/10/2015 15:00	1.5 (1.6)	2.4 (2.8)	5.6	A pre-frontal trough in the west resulted in a north westerly airstream being directed into the southeast of the continent.

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.

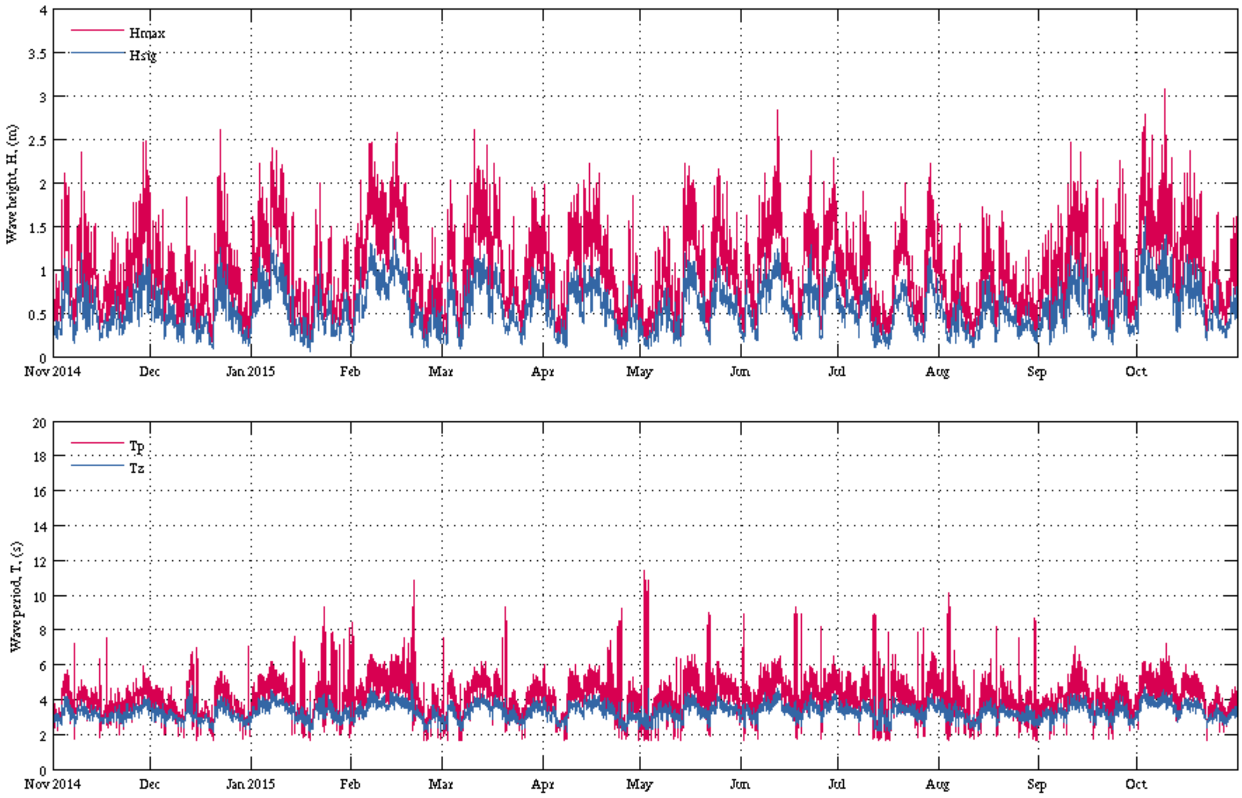


Figure 95 Abbot Point – Daily wave recordings

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

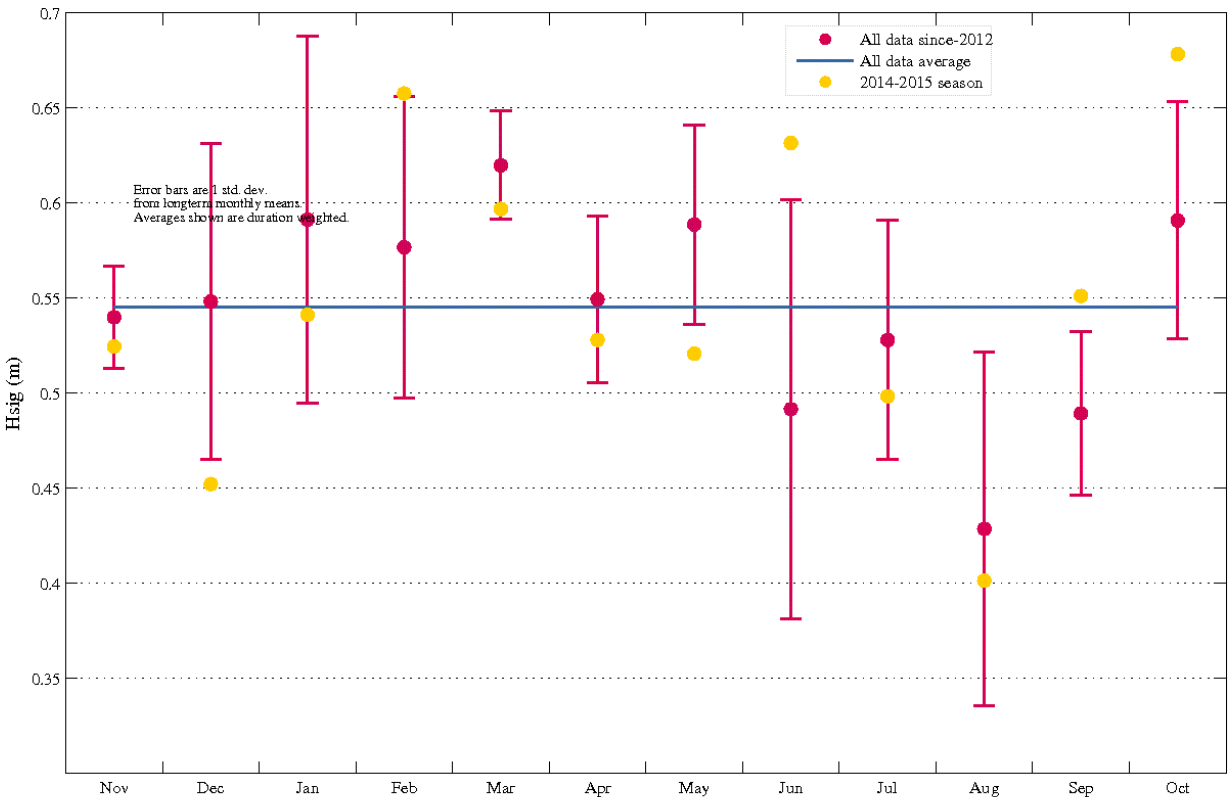


Figure 97 Abbot Point – Monthly average wave height (Hsig) for seasonal year and for all data

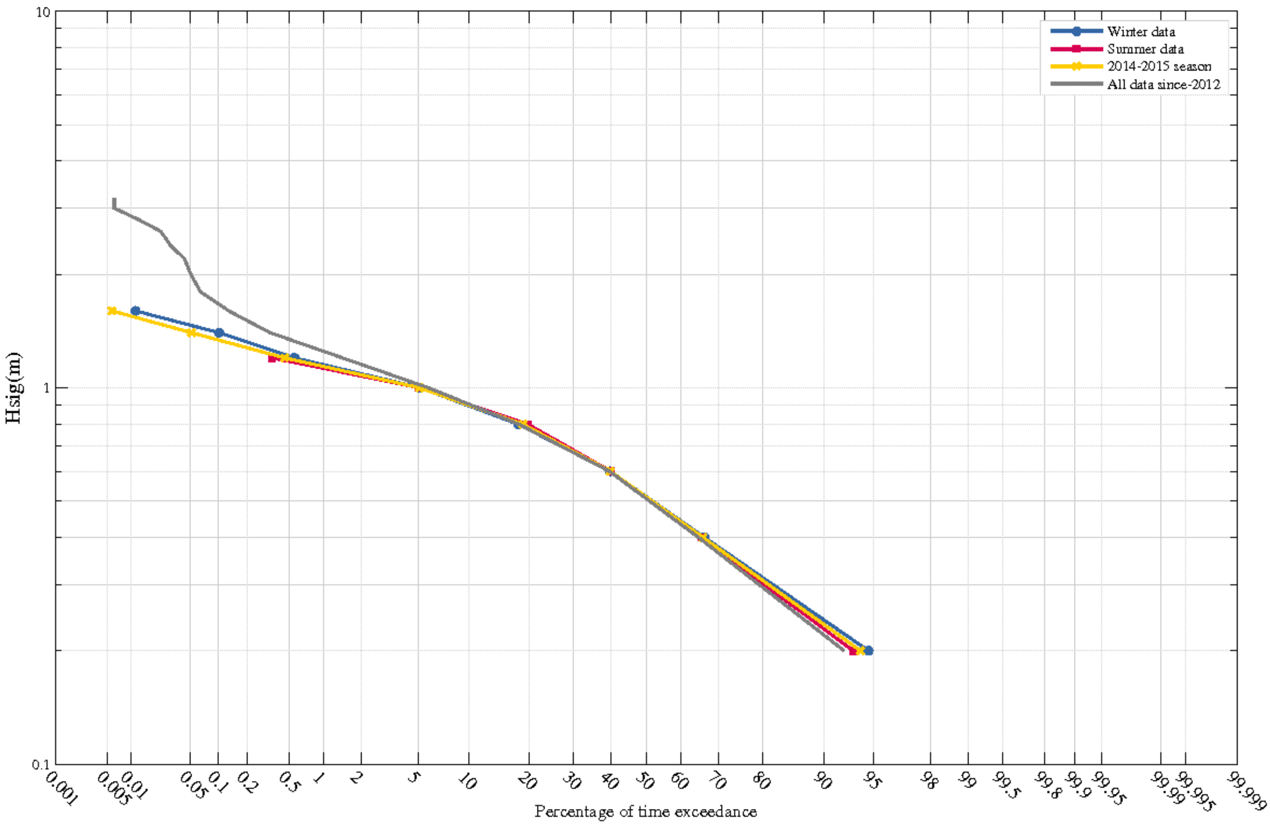


Figure 98 Abbot Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

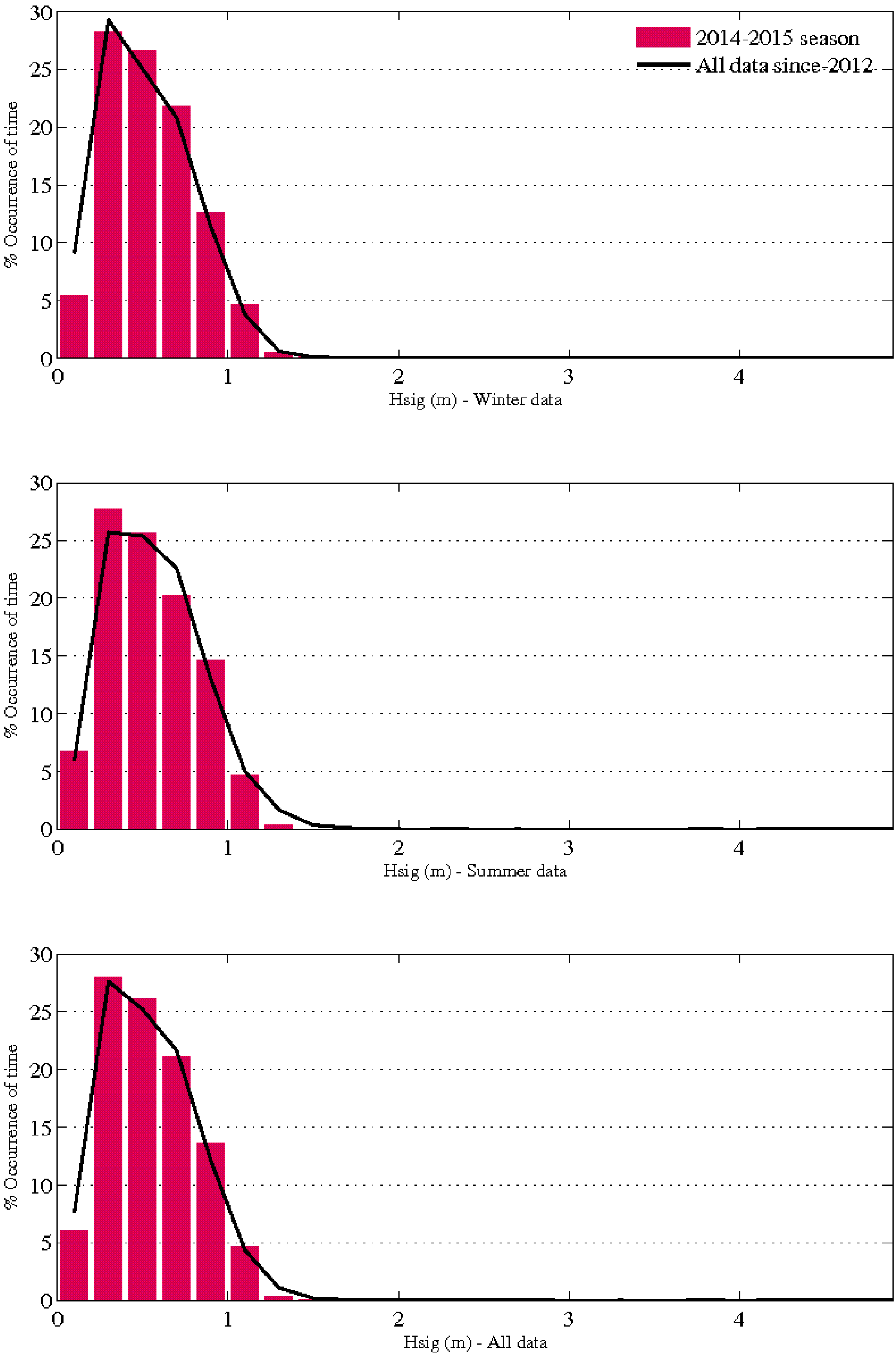


Figure 99 Abbot Point – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

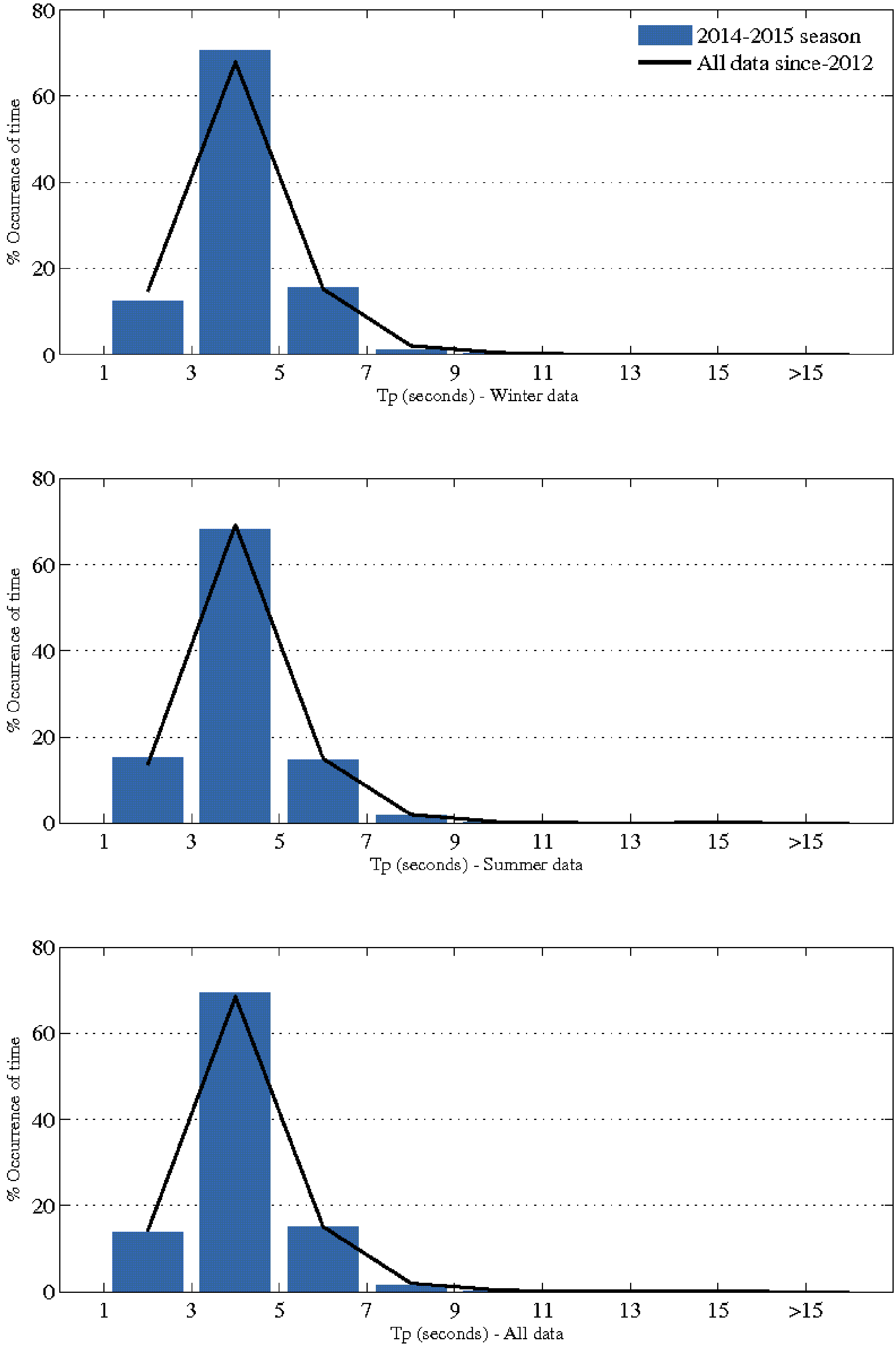


Figure 100 Abbot Point – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

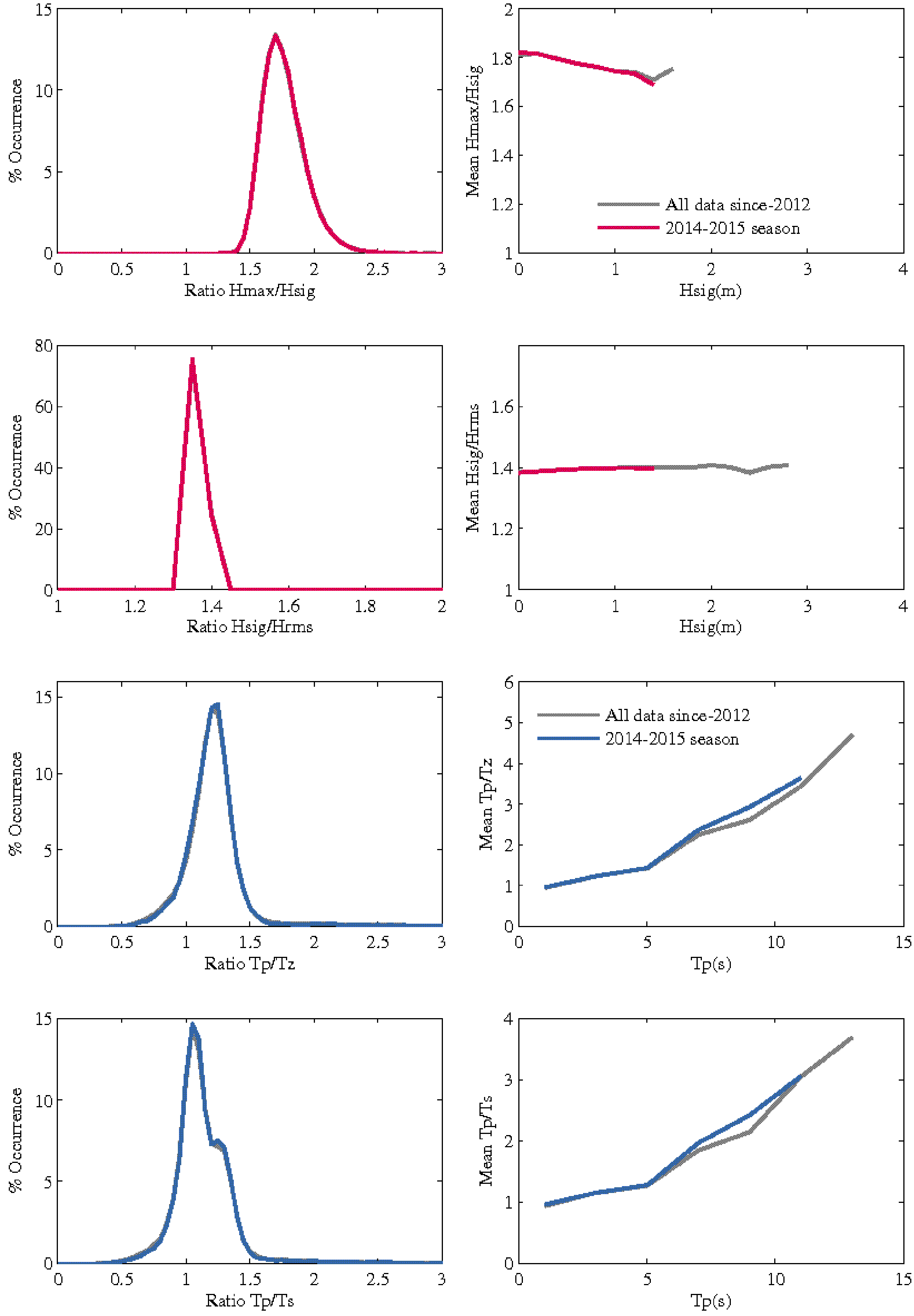
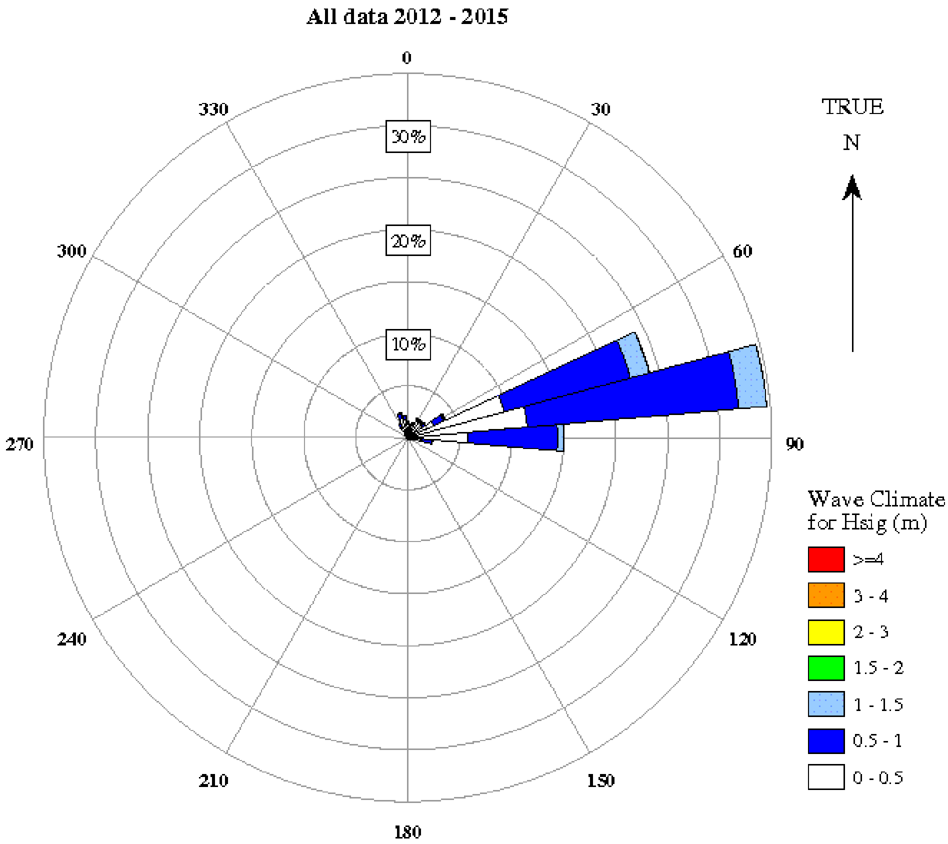


Figure 101 Abbot Point – Wave parameter relationships



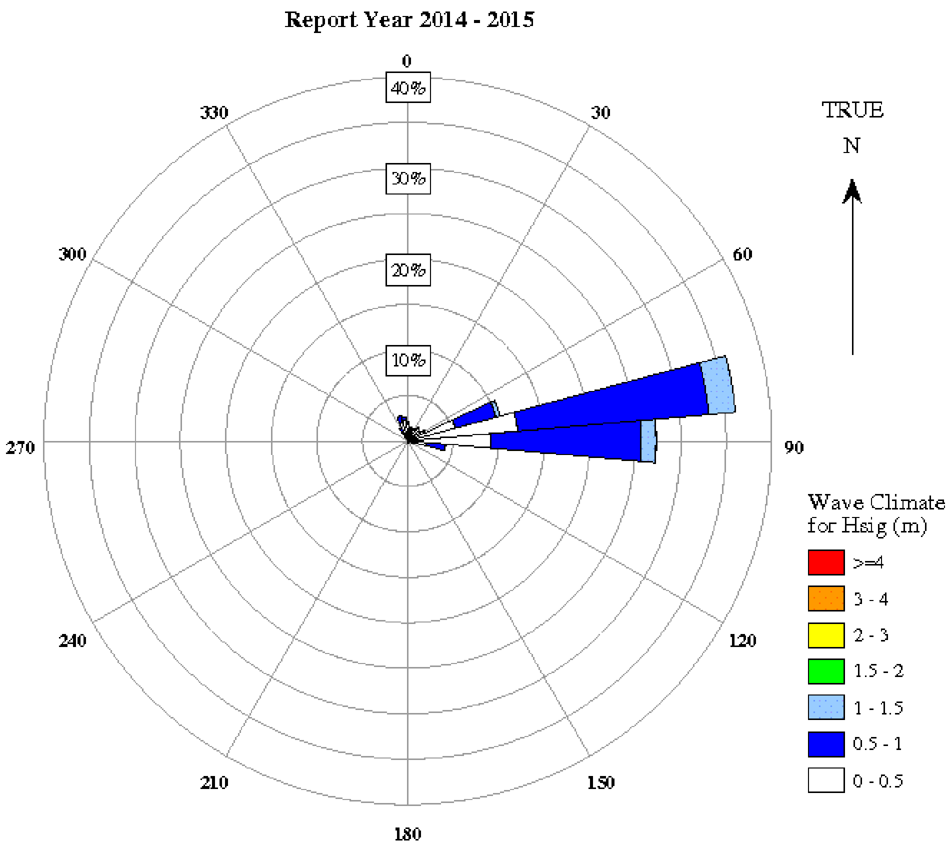


Figure 102 Abbot Point – Directional wave rose

7.12 Townsville

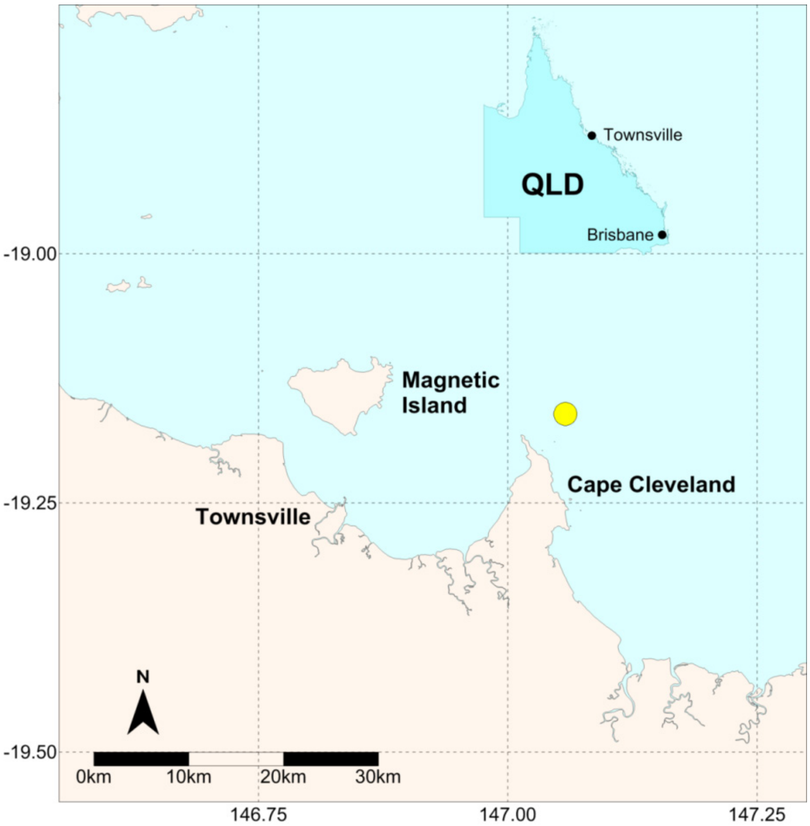


Figure 103 Townsville – Locality plan

Table 49 Townsville – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	20/11/1975	na	314,930	39.9
2014–15	01/11/2014	3.15 days	17,368	1

Table 50 Townsville – Buoy deployments during the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
19°09.576'S	147°03.515'E	16	23/07/2014	18/12/2015
19°09.576'S	147°03.515'E	16	18/12/2015	current

7.12.1 Townsville – seasonal overview

The Townsville wave buoy has been operational for nearly 40 years. The data recorded for the period November 2014 to October 2015 experienced excellent data return. There was a total gap of 3.15 days, equivalent to 99.1 per cent data return (Table 49). The buoy was replaced once during the reporting period on 18 December (Table 50).

The largest waves during the reporting period occurred in October as a north westerly airstream being directed into the southeast of the continent (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 4m for Hmax and not above 2 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 20.5 °C to 32 °C (Figure 105) where the SST was high enough for tropical cyclone development throughout summer months, including November, March, April and mid May.

Monthly average Hsig (Figure 106) was within one standard deviation (sd) for almost the entire data record, except for December, June and October. June and October experienced wave heights larger than +1 sd and December 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 highest waves. Histograms for percentage occurrence of Hsig (Figure 108) and peak wave period (Tp) (Figure 109) also displayed the same similarity 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 9:27	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 6:30	2.7	01/02/1986 20:49	4.9

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
3/10/2015 19:00	1.9 (2.1)	3.5 (4.2)	6.3	A pre-frontal trough in the west resulted in a north westerly airstream being directed into the southeast of the continent.

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.

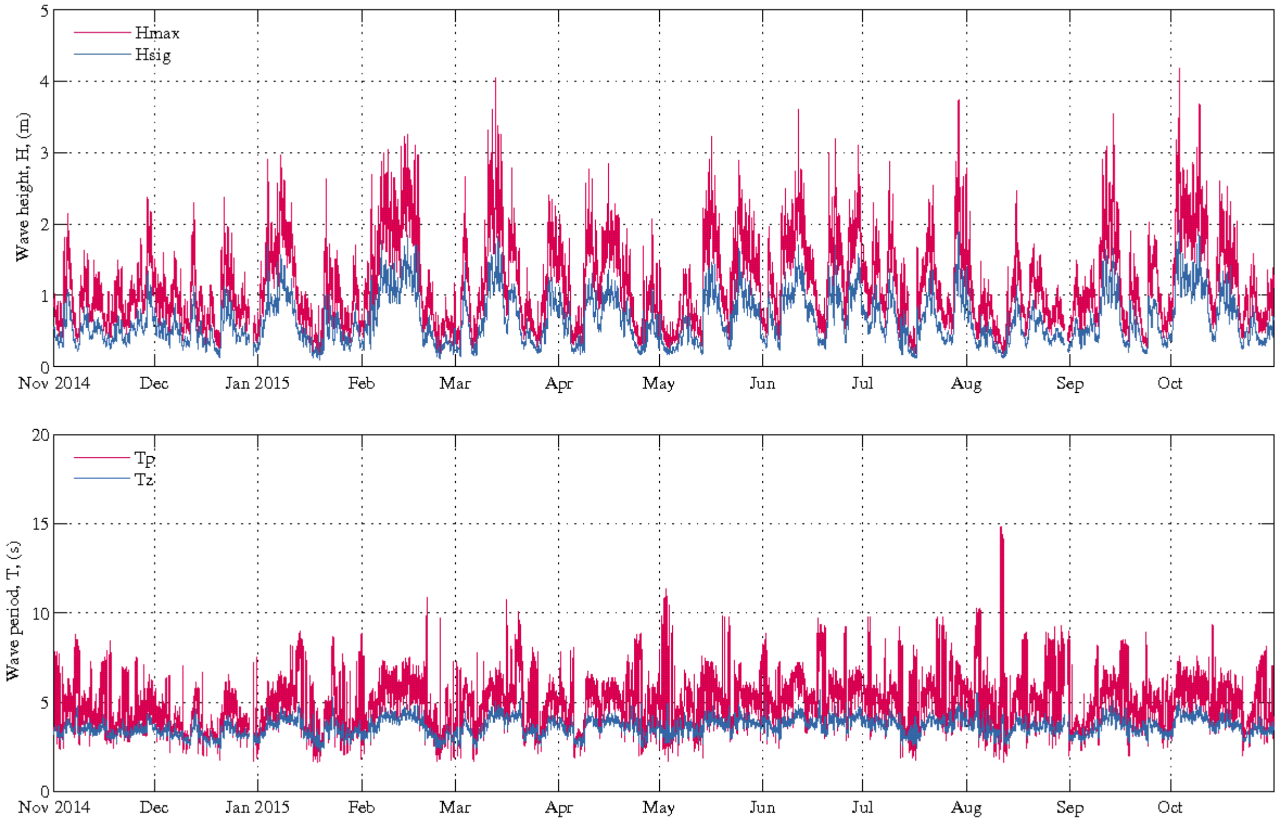


Figure 104 Townsville – Daily wave recordings

Figure 105 Townsville – Sea surface temperature and peak wave directions

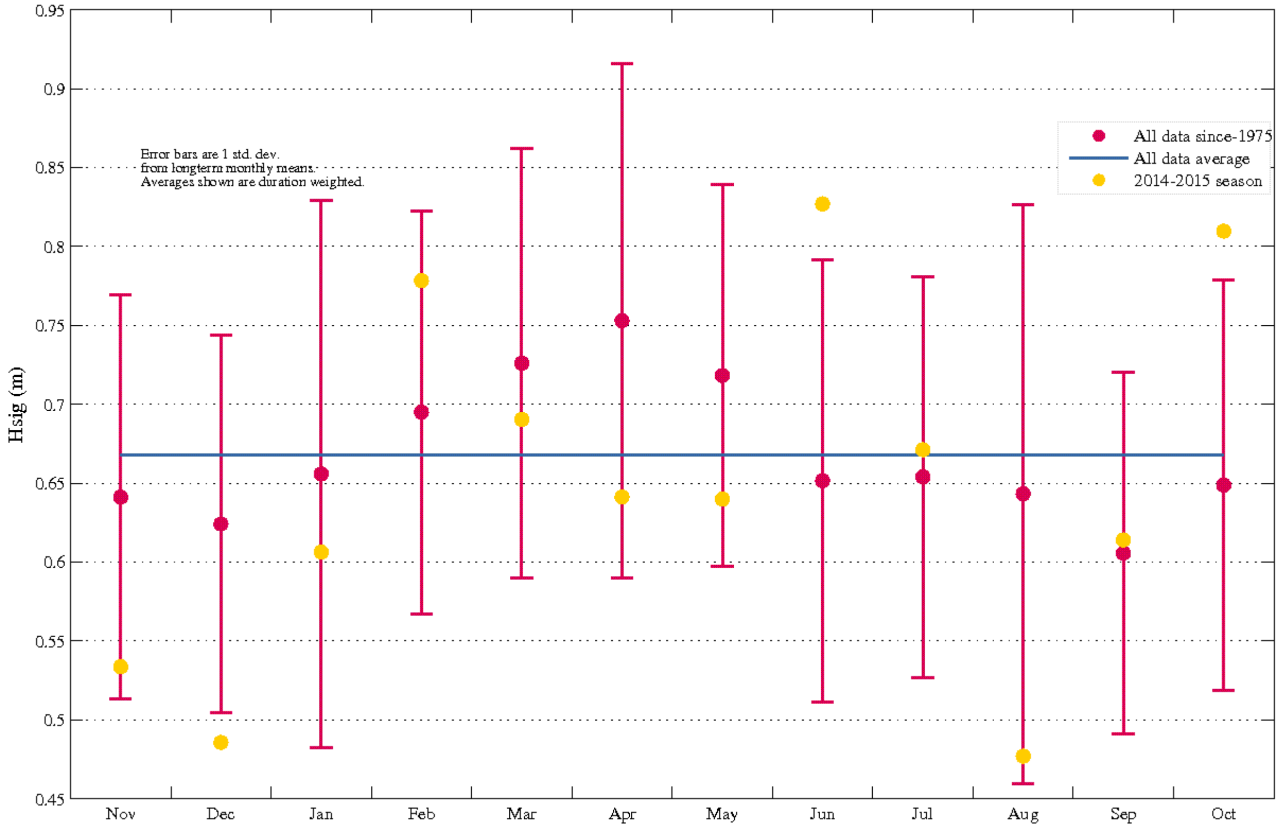


Figure 106 Townsville – Monthly average wave height (Hsig) for seasonal year and for all data

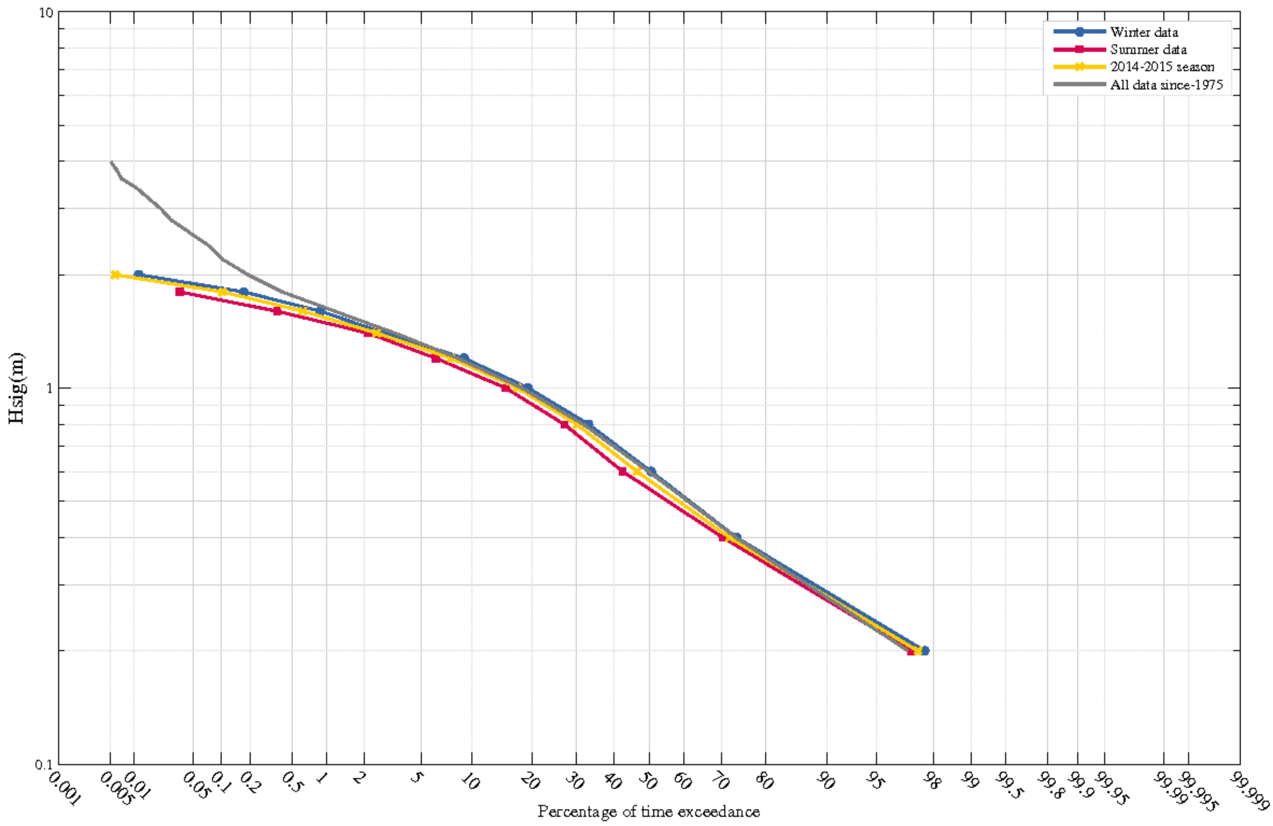


Figure 107 Townsville – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

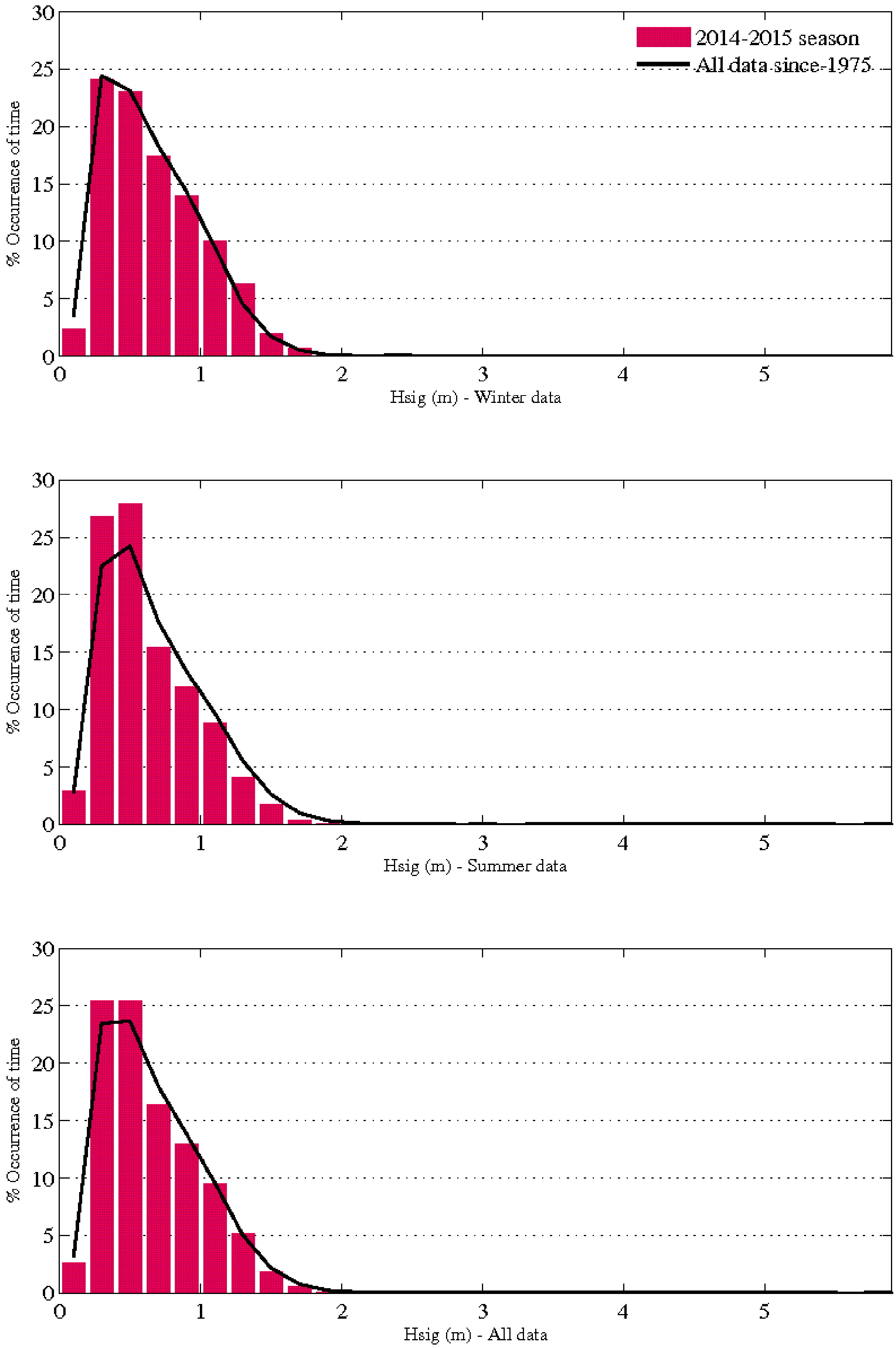


Figure 108 Townsville – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

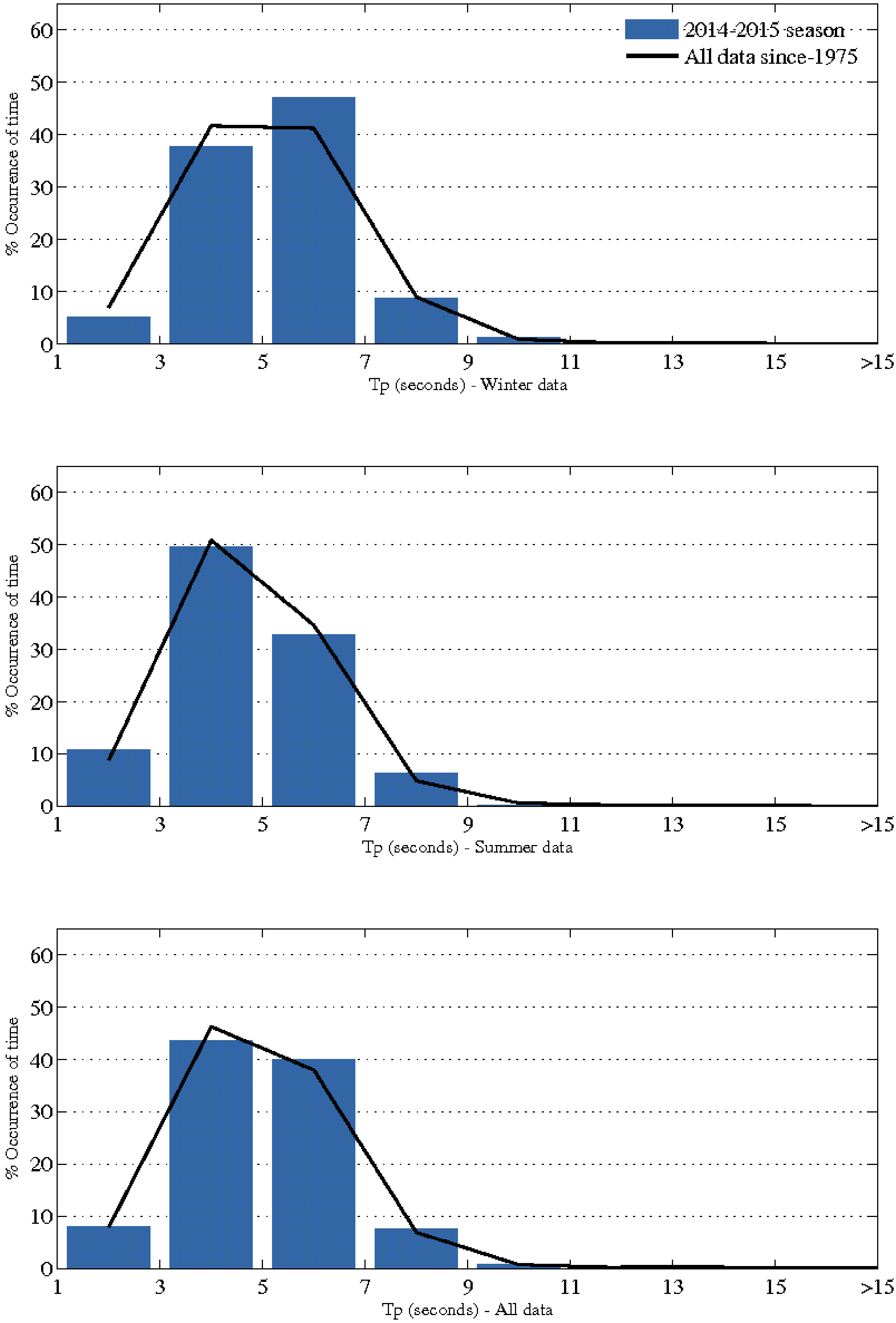


Figure 109 Townsville – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

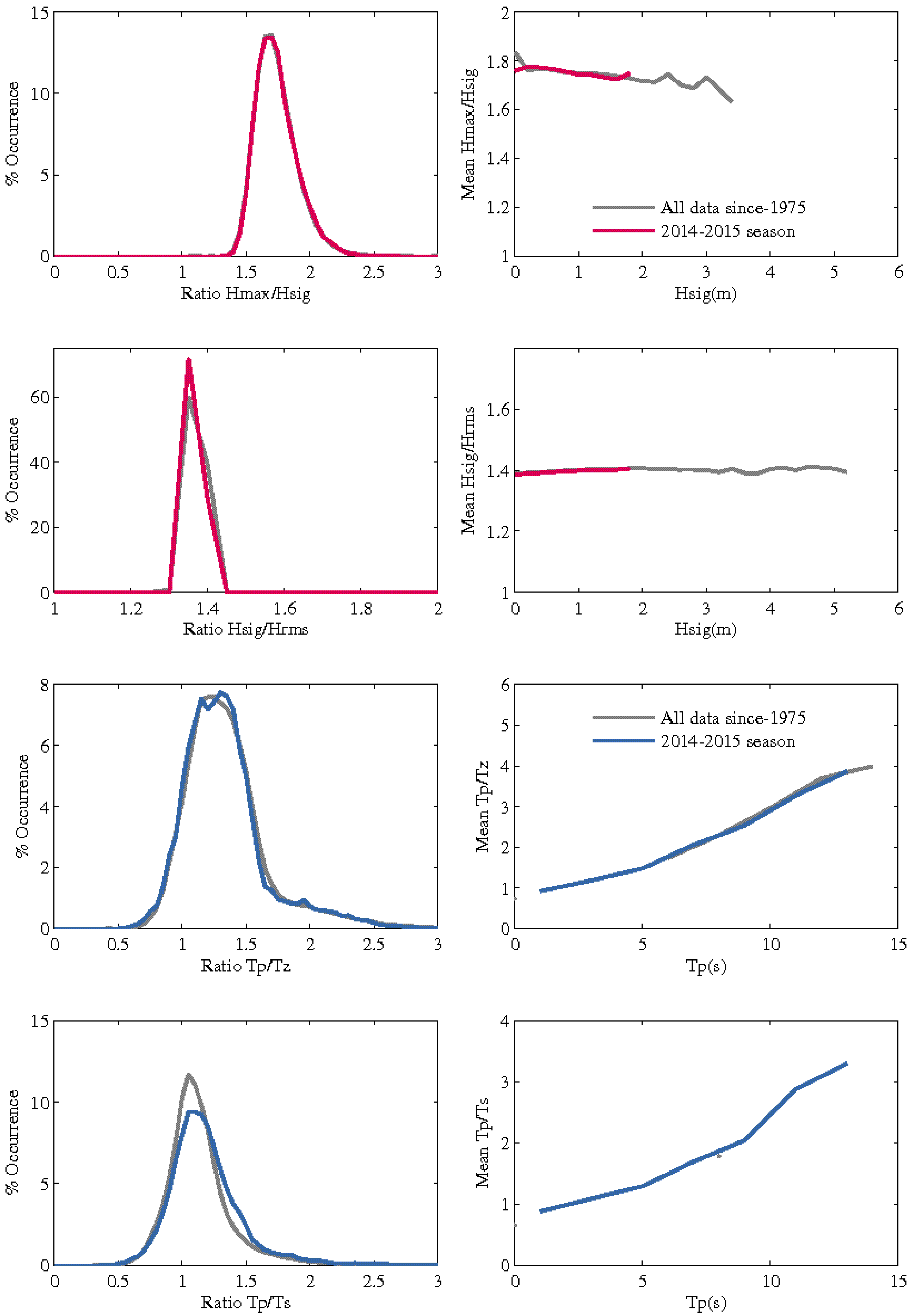
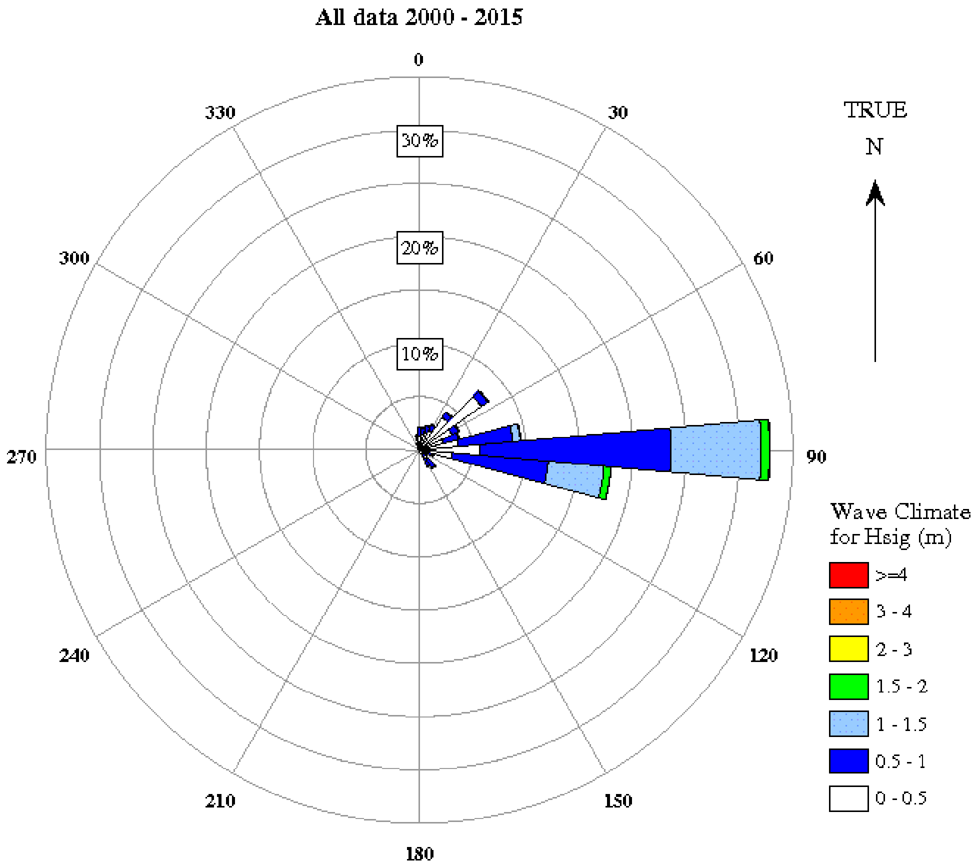


Figure 110 Townsville – Wave parameter relationships



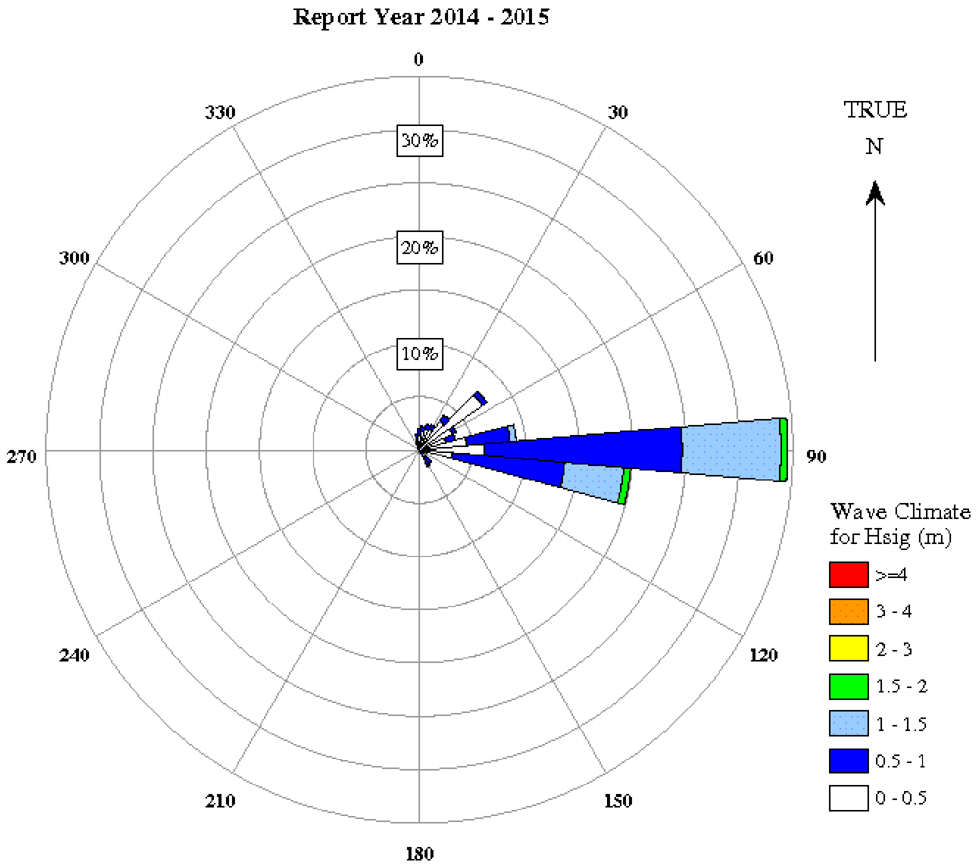


Figure 111 Townsville – Directional wave rose

7.13 Cairns

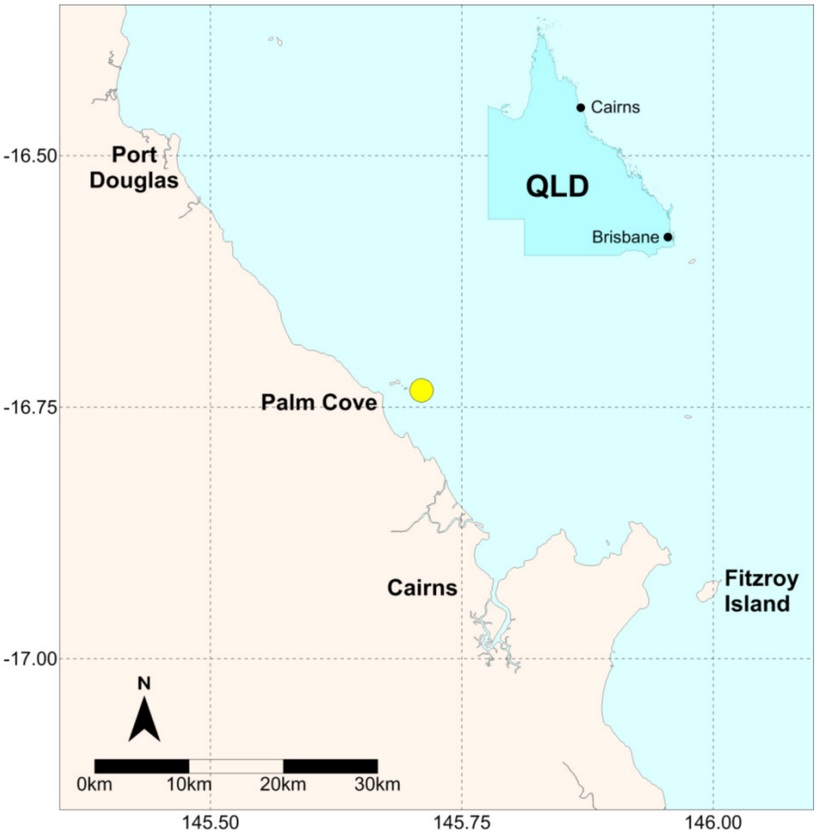


Figure 112 Cairns – Locality plan

Table 53 Cairns – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	04/05/1975	na	325,169	40.5
2014–15	01/11/2014	1.69 days	17,438	1

Table 54 Cairns – Buoy deployments for the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
16°44.830' S	145.42.910' E	12	05/02/2014	24/02/2015
16°44.020' S	145.42.600' E	11	24/02/2015	current

7.13.1 Cairns – seasonal overview

The Cairns wave buoy has been operational for 40.5 years. The data recorded for the period November 2014 to October 2015 only had gaps of 1.69 days, equivalent to 99.5 per cent data return (Table 53). The buoy was replaced once during the reporting period on 24 February (Table 54).

The wave buoy measured two significant meteorological events, severe TC Pam and TC Nathan (DSITI 2015a), both during the month March (Table 56). The two events were not strong enough to generate higher waves than the top 10 highest waves.

Figure 113 shows the daily wave Height and period. There are significant peaks in the wave height plot during the month March from the two cyclones. The wave period stays fairly constant.

Recording of sea surface temperature (SST) failed from November until the end of February, due to a wave buoy without a temperature sensor. On 24 February the wave buoy was replaced and recorded the temperature again. The SST was above 26 degrees during the months of March, April and mid May, and during a few days in September.

The current buoy deployed at Cairns is a non-directional buoy and doesn't measure wave direction. Therefore no directional wave data for Cairns has been presented or commented on in this report.

The monthly average Hsig (Figure 115) was within one standard deviation (sd) of the historic monthly mean, with exception of February, March, June and October. The average value in those months are recorded above the +1sd. The percentage exceedance of Hsig for all wave periods (Figure 116) was similar to the historical data. There was a notable difference in the height of waves during the winter months, the highest waves occurred 4 per cent more often than the historical data.

Histograms of percentage occurrence of time for Hsig (Figure 117) and for peak wave period (Tp) (Figure 118) show similarity 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.

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 3:00	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
14/03/2015 06:30	1.5 (1.6)	2.4 (2.9)	4.8	Severe Tropical Cyclone Pam passed through the eastern Coral sea
20/03/2015 04:30	1.5 (1.6)	2.6 (2.9)	8.7	Tropical Cyclone Nathan made landfall just north of Cape Flattery on the 20th March.

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

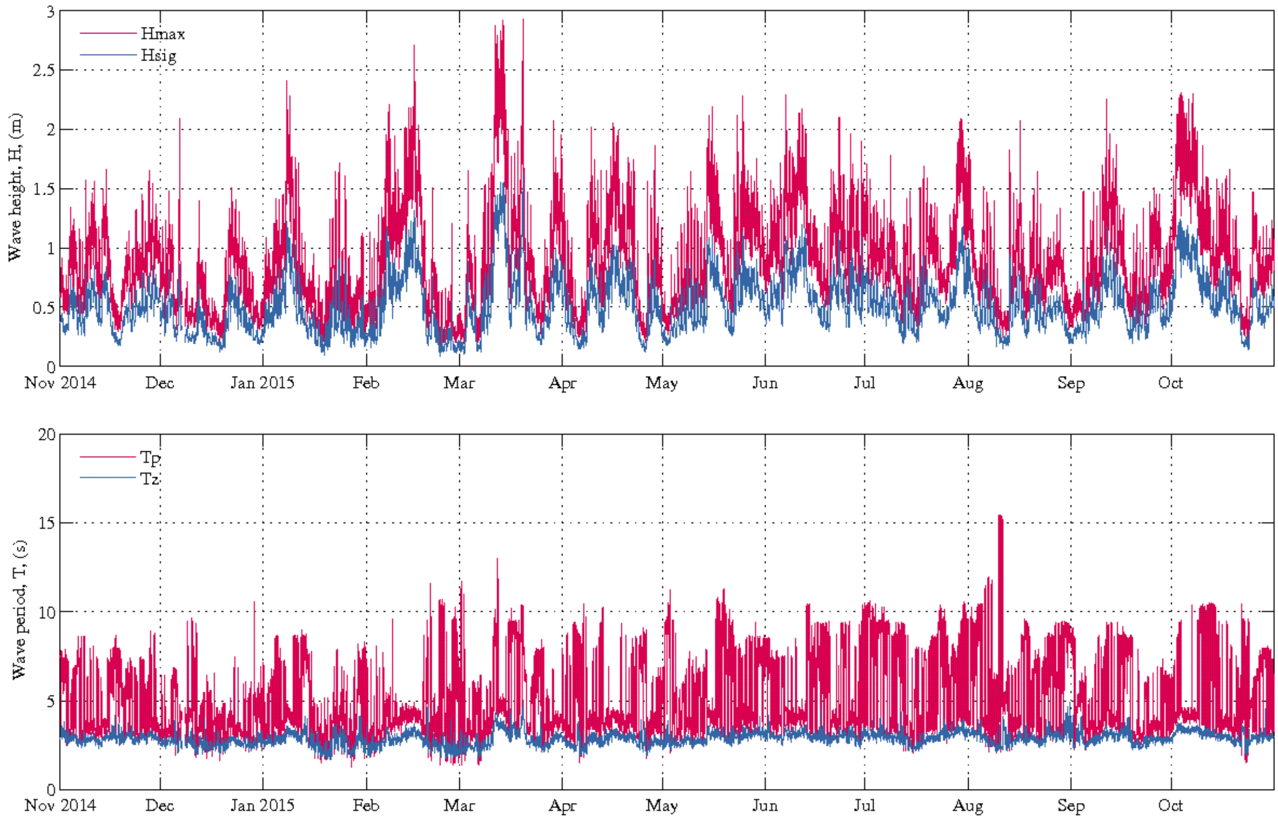


Figure 113 Cairns – Daily wave recordings

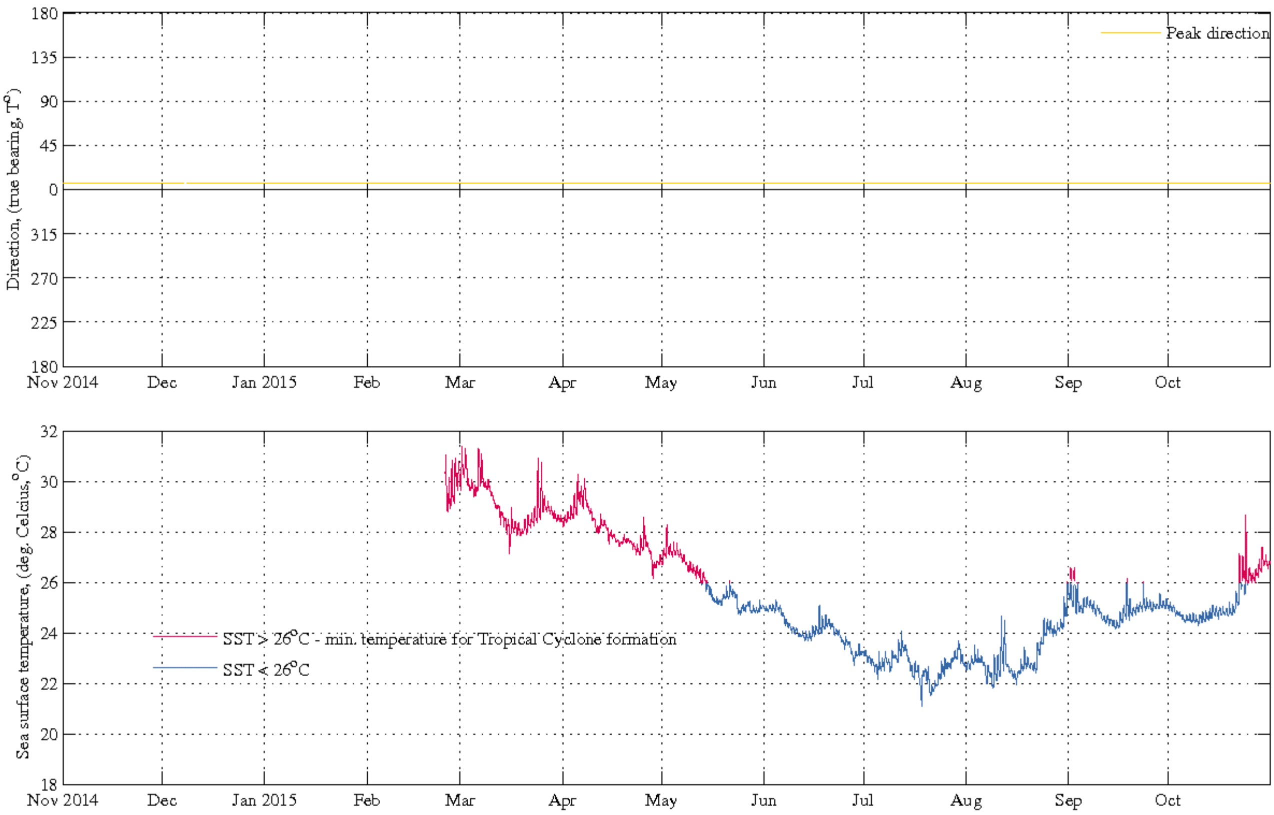


Figure 114 Cairns – Daily Sea surface temperature

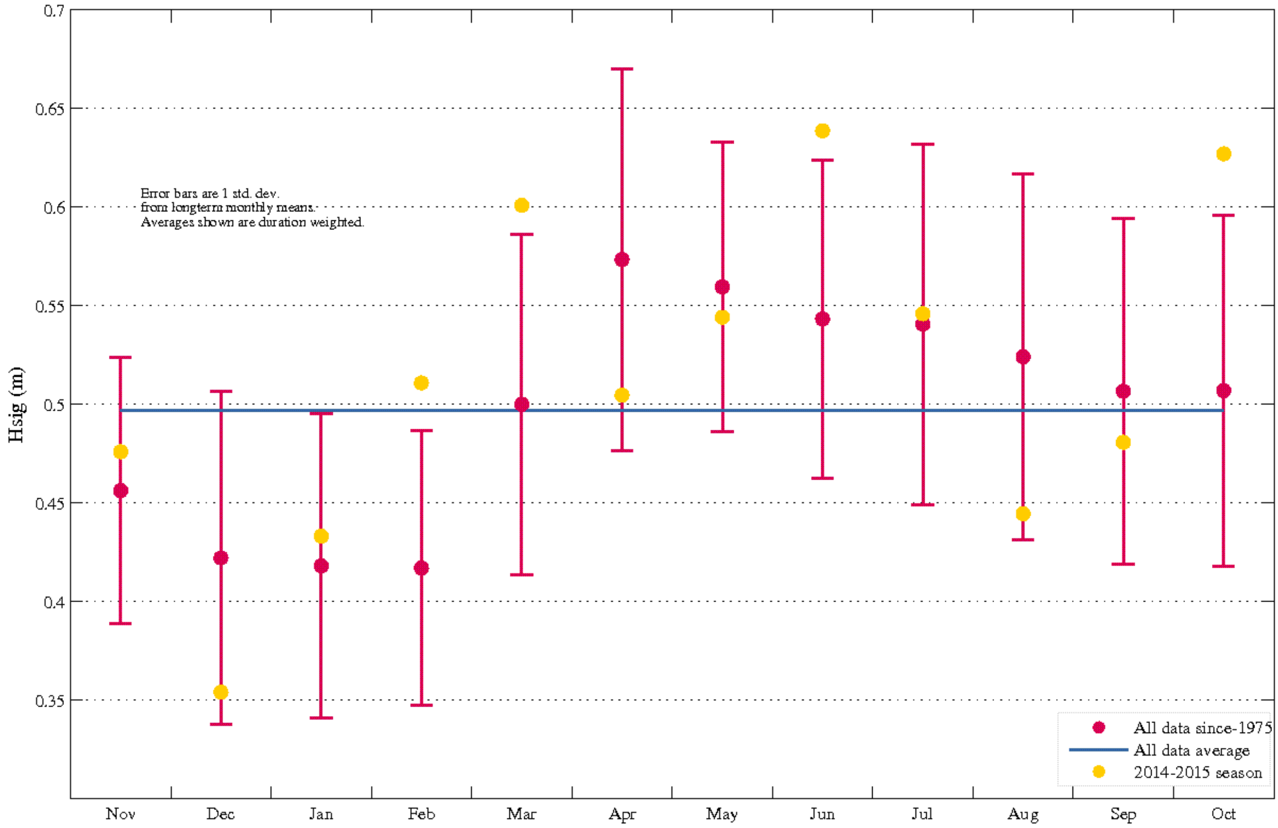


Figure 115 Cairns – Monthly average wave height (Hsig) for seasonal year and for all data

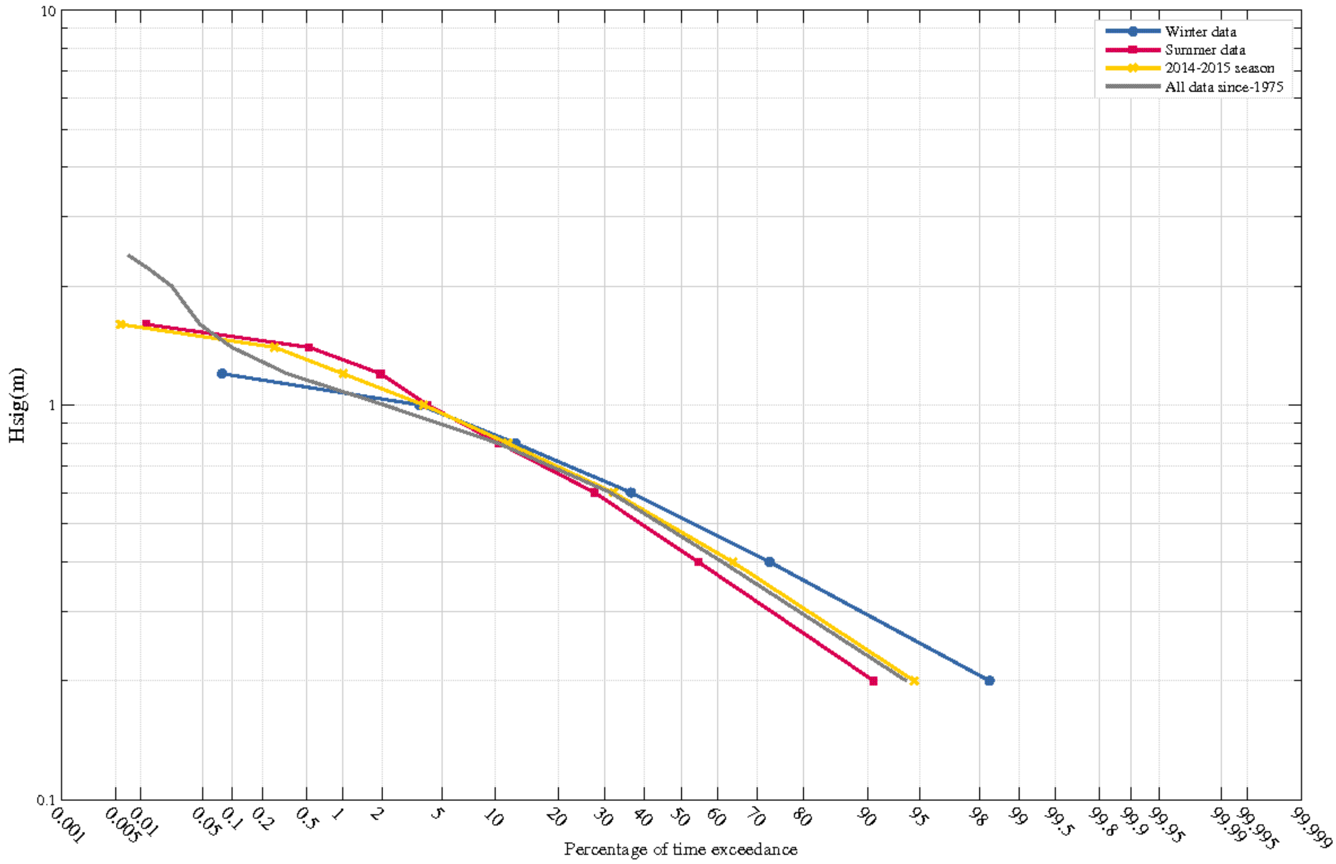


Figure 116 Cairns – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

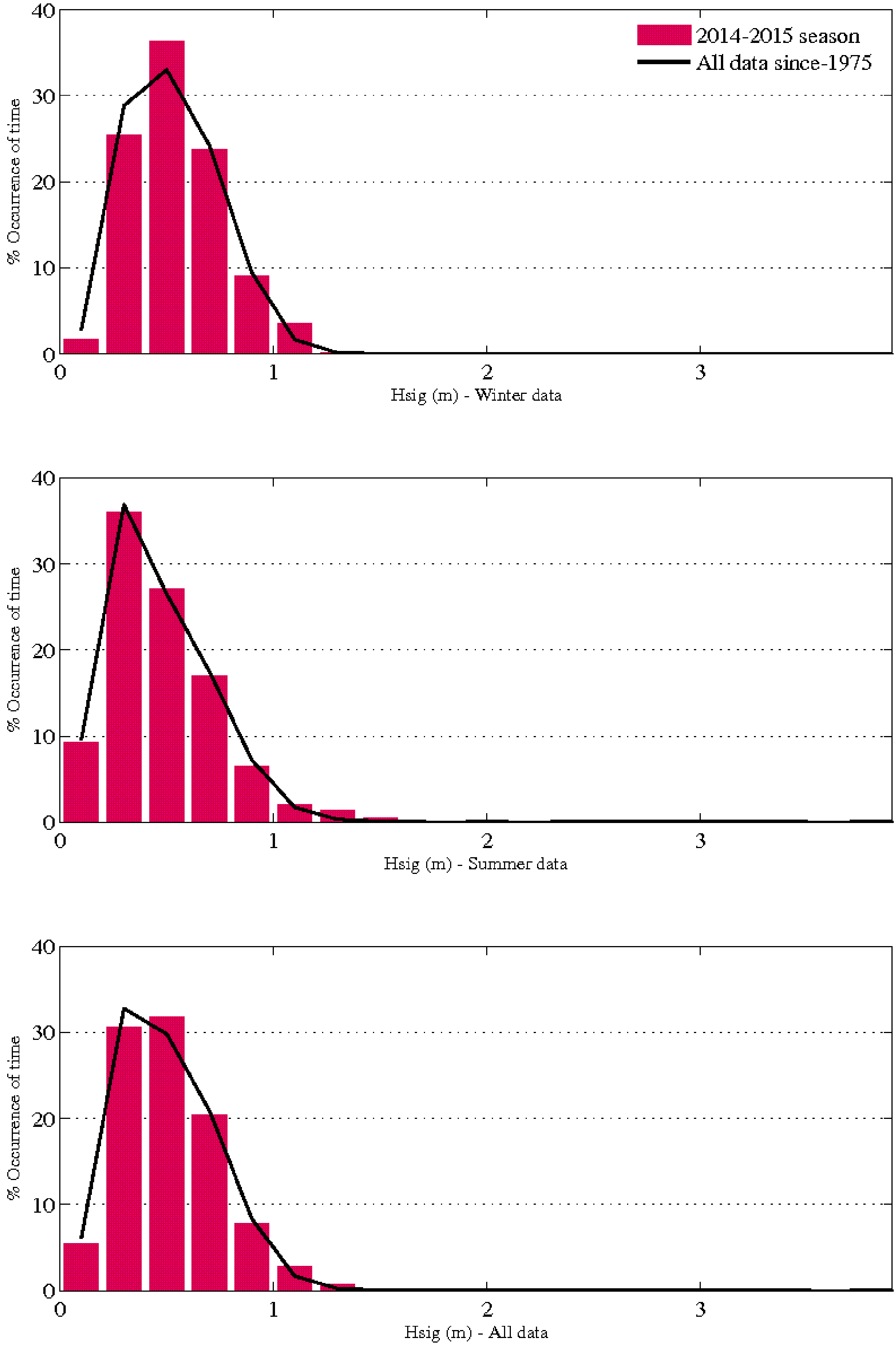


Figure 117 Cairns – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

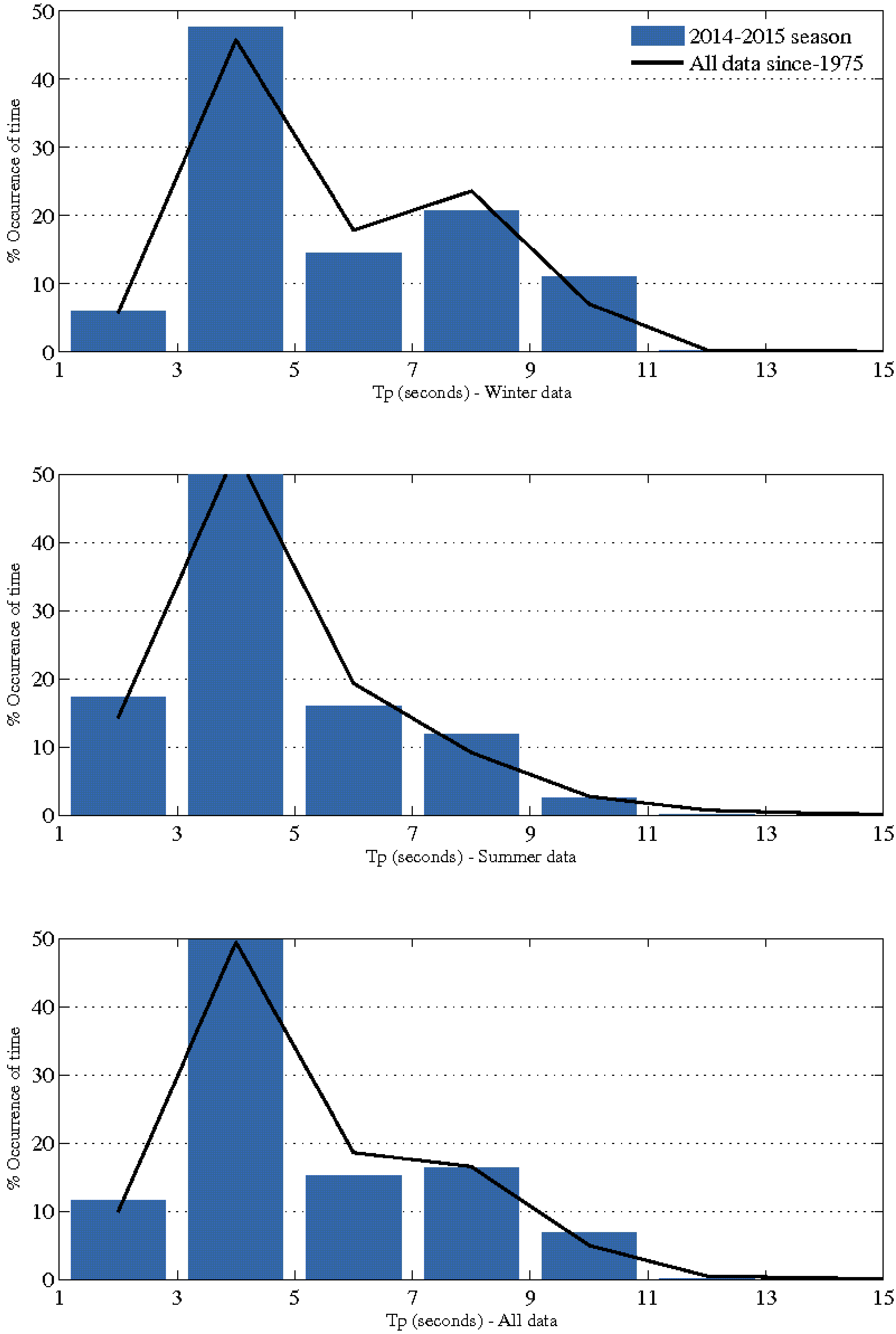


Figure 118 Cairns – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

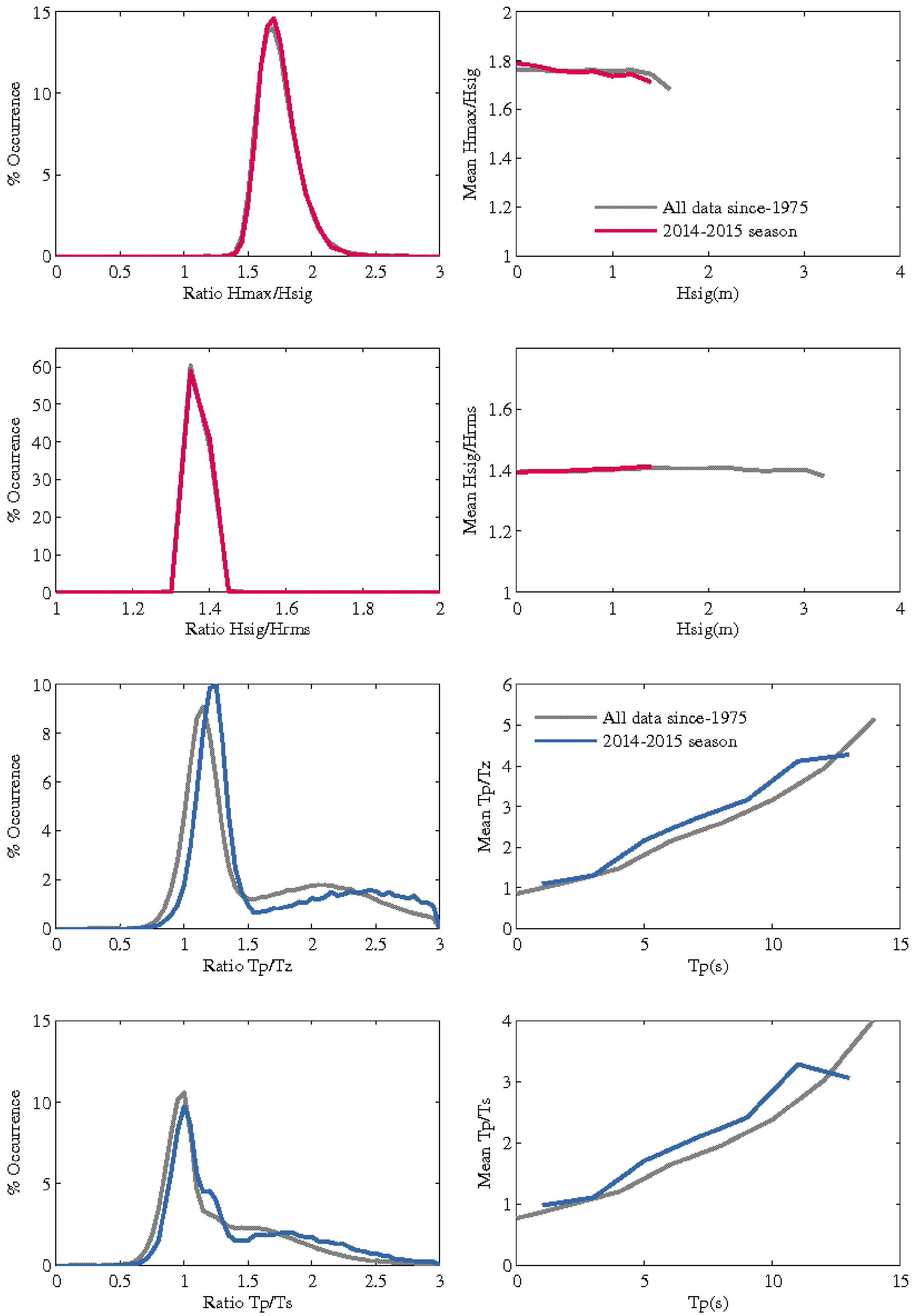


Figure 119 Cairns – Wave parameter relationships

7.14 Albatross Bay

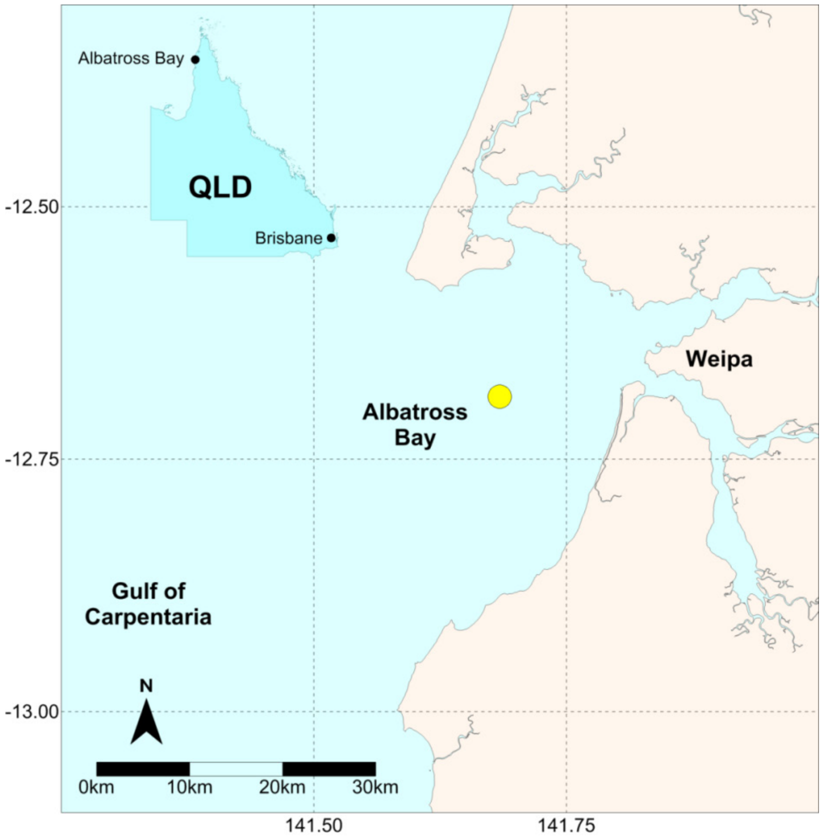


Figure 120 Albatross Bay – Locality plan

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	114,576	6.93
2014–15	01/11/2013	12.71 days	16,909	1

Table 58 Albatross Bay – Buoy deployments for the 2014-15 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
12°41.280'S	141°41.080'E	10	11/07/2014	current

7.14.1Albatross Bay – seasonal overview

The Albatross Bay wave buoy has been operational for just under seven years with an overall data return of 98.5 per cent. The data record for the period November 2014 to October 2015 was good, with total gaps of about 12.71 days, equivalent to 96.5 per cent data return (Table 57). The buoy hasn't been replaced during the recorded period (Table 58).

High ranking significant (Hsig) and maximum (Hmax) wave heights were recorded during a low pressure system on 09 January. The recorded highest wave heights were, Hmax 5.4 m and Hsig 2.2 m, respectively ranked 4 and 9 (Table 59). Another low pressure system has been recorded on 22 January, however the wave heights weren't significant enough to be ranked in the top 10 highest waves (Table 60). Distinct peaks are shown in Figure 121 during the events in January.

The Sea Surface Temperature (SST) measured in the buoy hull shows the recorded values ranged from 25 °C to 33.5 °C during the reported year. The SST was high enough for tropical cyclone development for most of the year, except for the end of June through to the end of August and a few days in October 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 November, January and February, average Hsig was greater than one standard deviation (sd) of the historic monthly mean (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 of the whole record (Figure 124), except for percentage of time exceedance for waves occurring less than 0.35 per cent of the time, where these less frequent waves have historically been larger. Figure 124 also illustrates a notable difference in recorded wave heights between winter and summer. Waves during winter are significantly smaller than during summer. This is also shown in the histograms of Hsig (Figure 125), the occurrence of time for the bin 0.2 m - 0.4 m during winter is 20 per cent higher than during summer. Histograms of Tp (Figure 126) were very similar between this season and the whole 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 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.

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 0:00	3.5	11/01/2009 23:30	5.7
3	30/01/2010 3:00	3.3	30/01/2010 5:30	5.5

4	02/02/20120 08:30	2.7	09/01/2015 08:30	5.4
5	19/03/2012 02:30	2.6	03/02/2012 09:00	5.1
6	19/02/2014 06:30	2.6	19/02/2014 07:30	5.0
7	29/12/2011 17:30	2.4	18/03/2012 19:30	4.3
8	22/01/2011 01:00	2.3	22/01/2011 06:00	4.2
9	09/01/2015 09:00	2.2	02/02/2009 09:30	4.0
10	09/03/2014 17:00	2.1	03/02/2014 15:30	3.9

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
09/01/2015 09:00	2.1 (2.2)	3.8 (5.4)	8.7	Low pressure system (1001 hPa) and trough extended across the top of north Queensland.
22/01/2015 17:00	1.6 (1.7)	2.8 (3.3)	7.5	Low pressure trough extending across northern territory into 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.

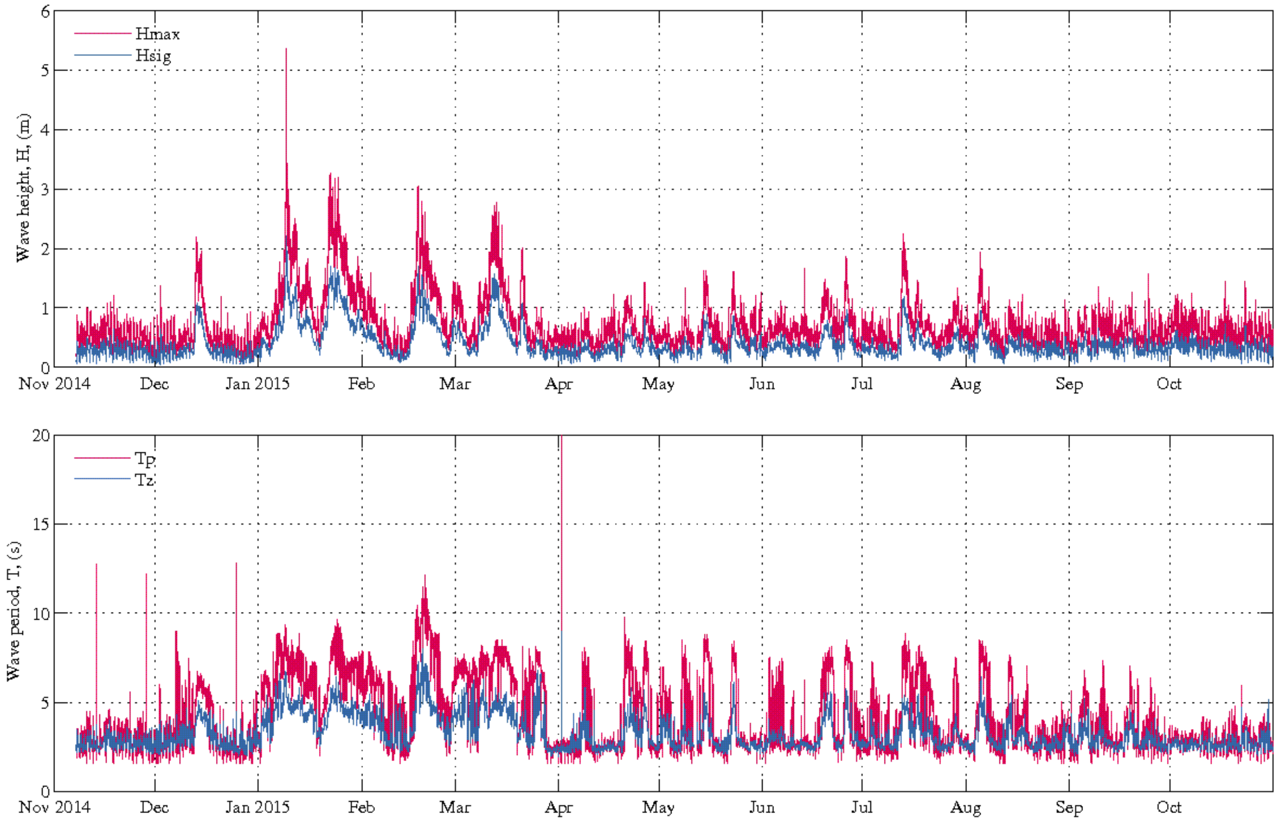


Figure 121 Albatross Bay – Daily wave recordings

Figure 122 Albatross Bay – Sea surface temperature and peak wave directions

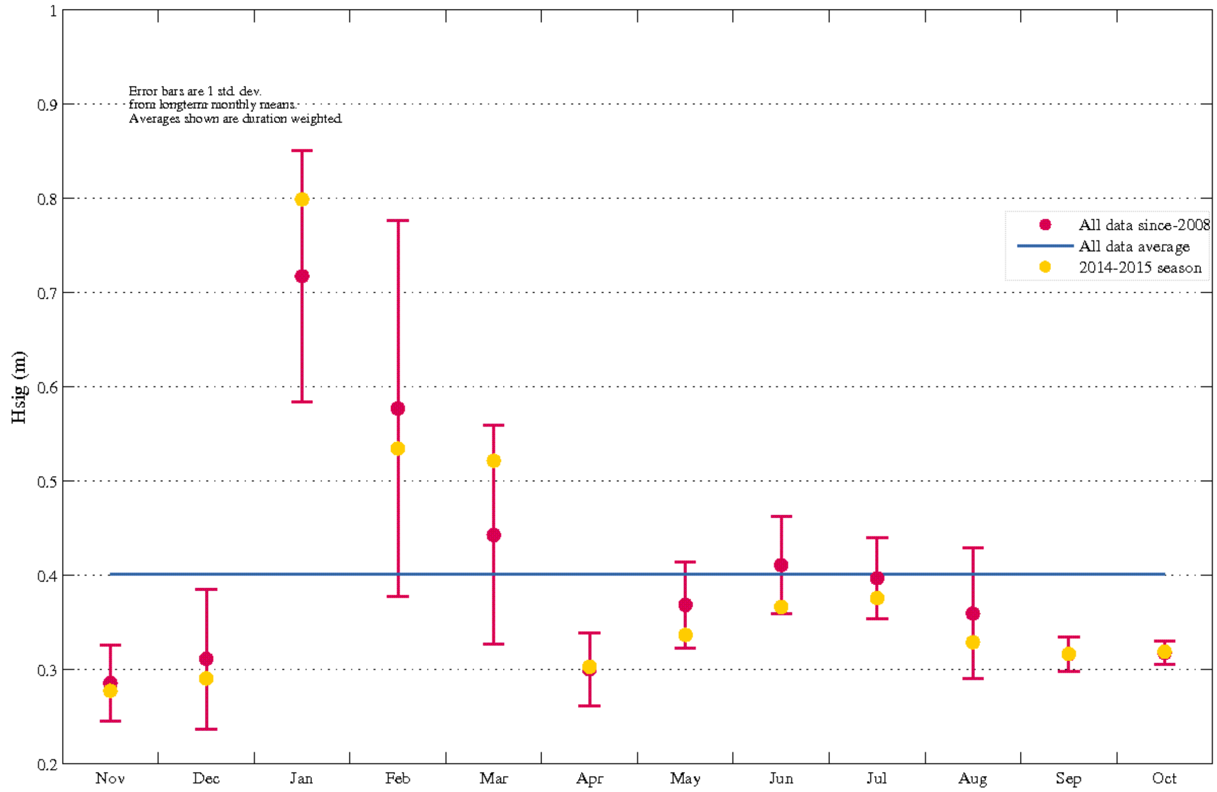


Figure 123 Albatross Bay – Monthly average wave height (Hsig) for seasonal year and for all data

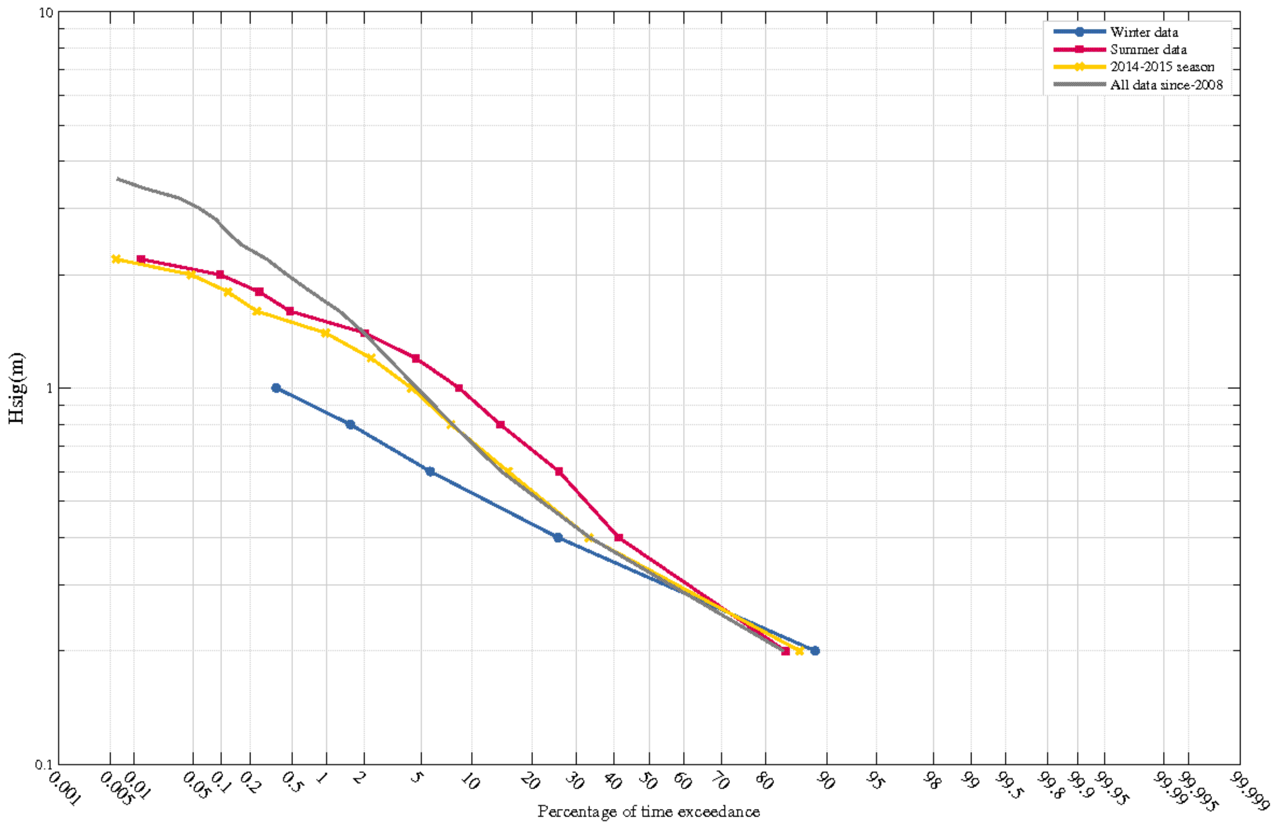


Figure 124 Albatross Bay - Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

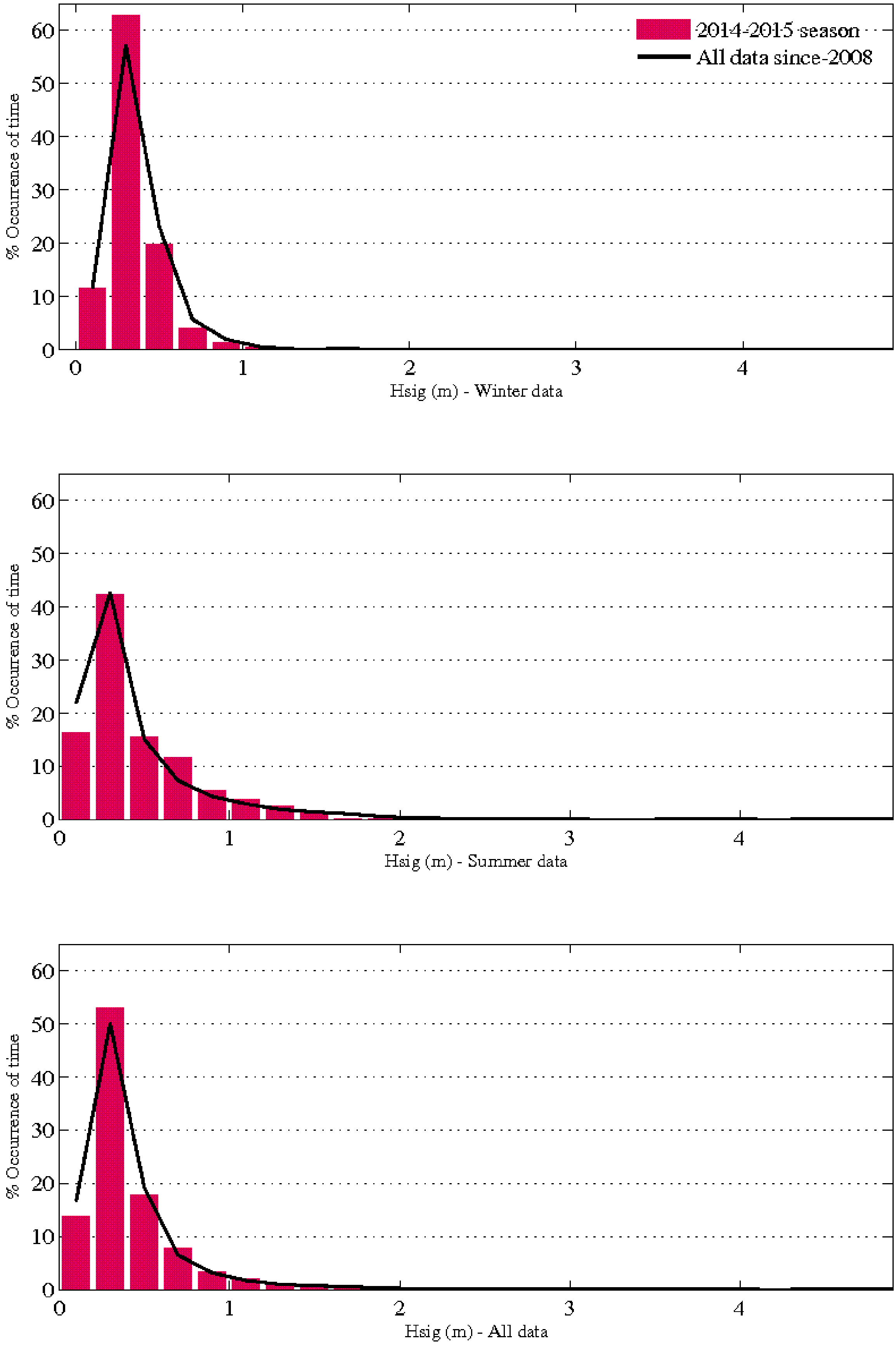


Figure 125 Albatross Bay – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

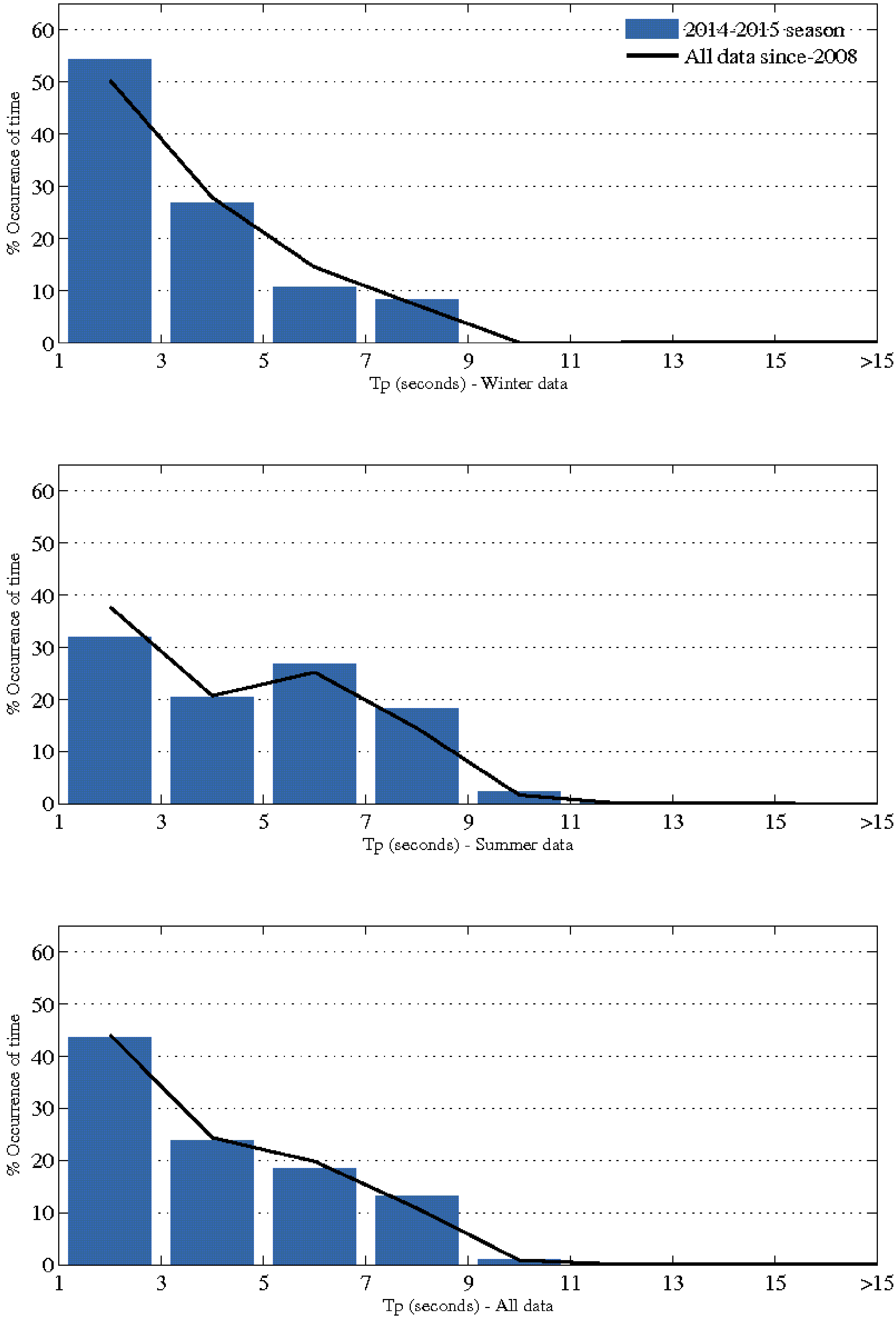


Figure 126 Albatross Bay – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

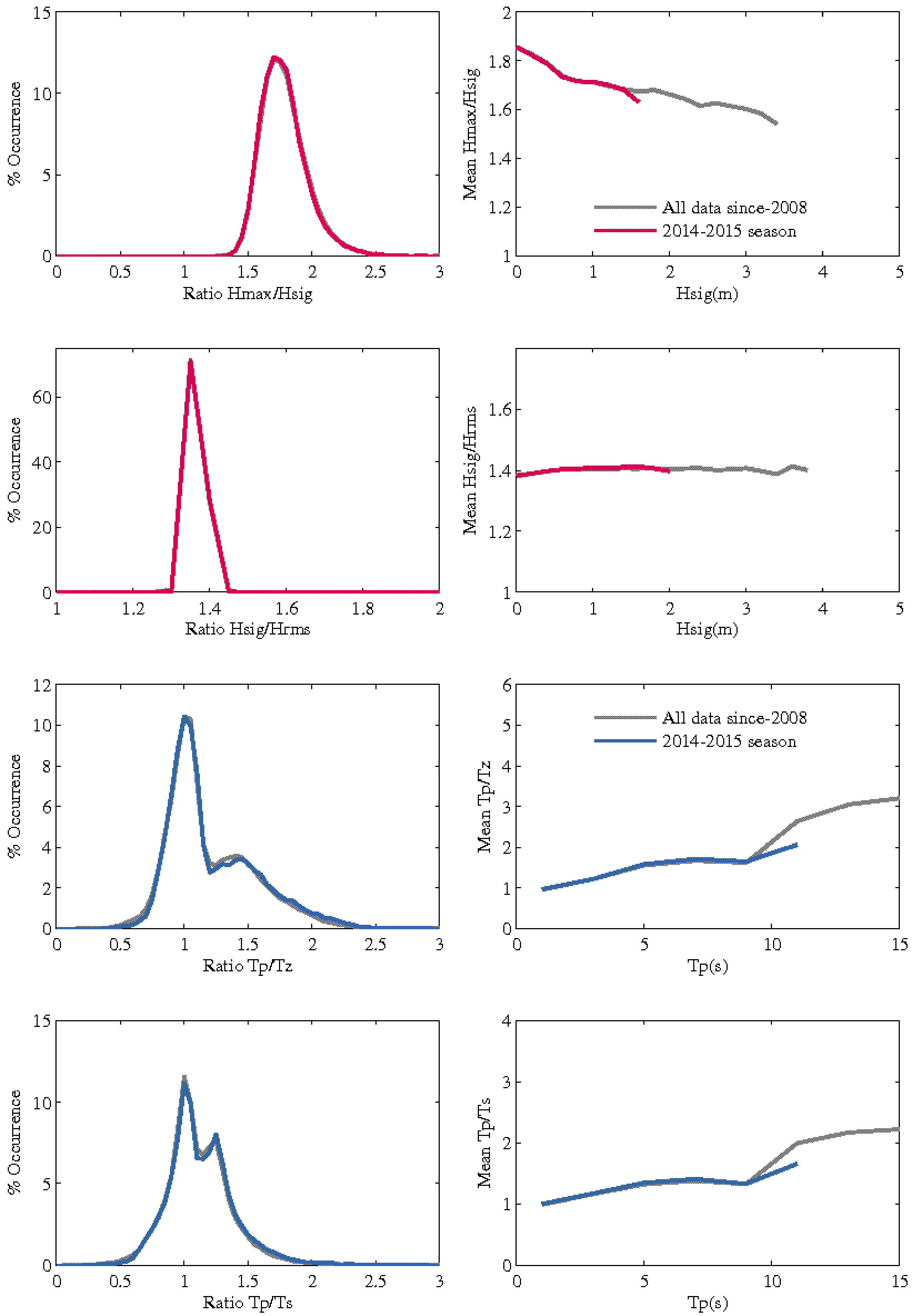
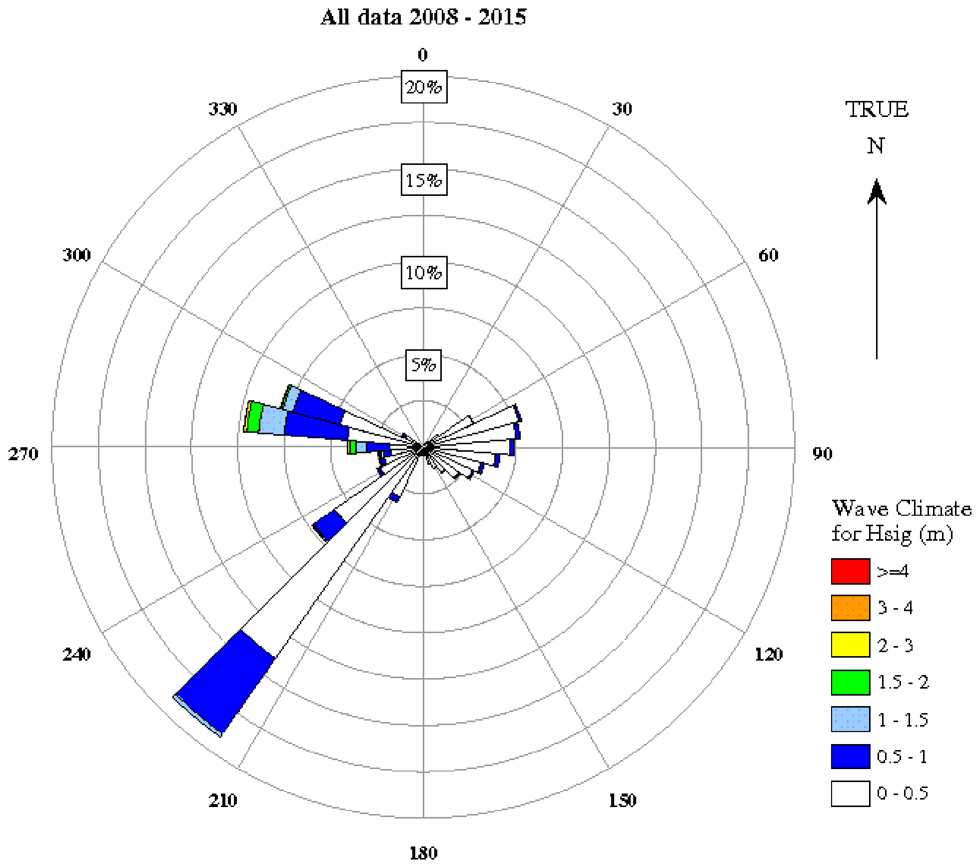


Figure 127 Albatross Bay – Wave parameter relationships



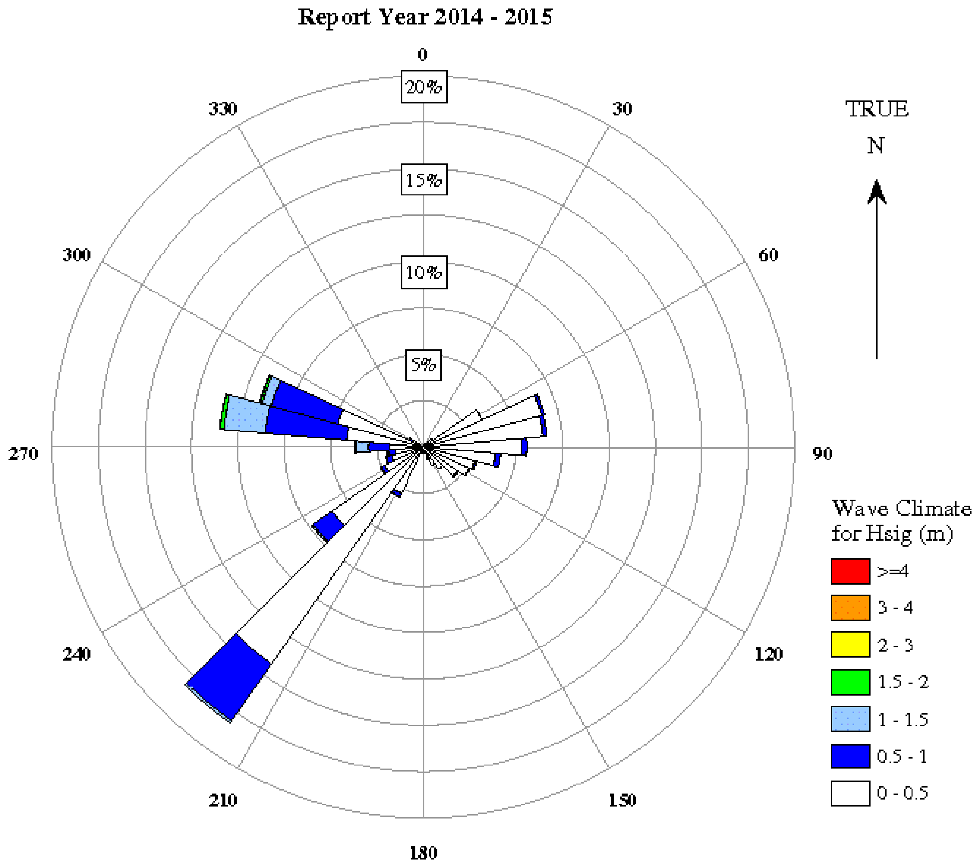


Figure 128 Albatross Bay – Directional wave rose

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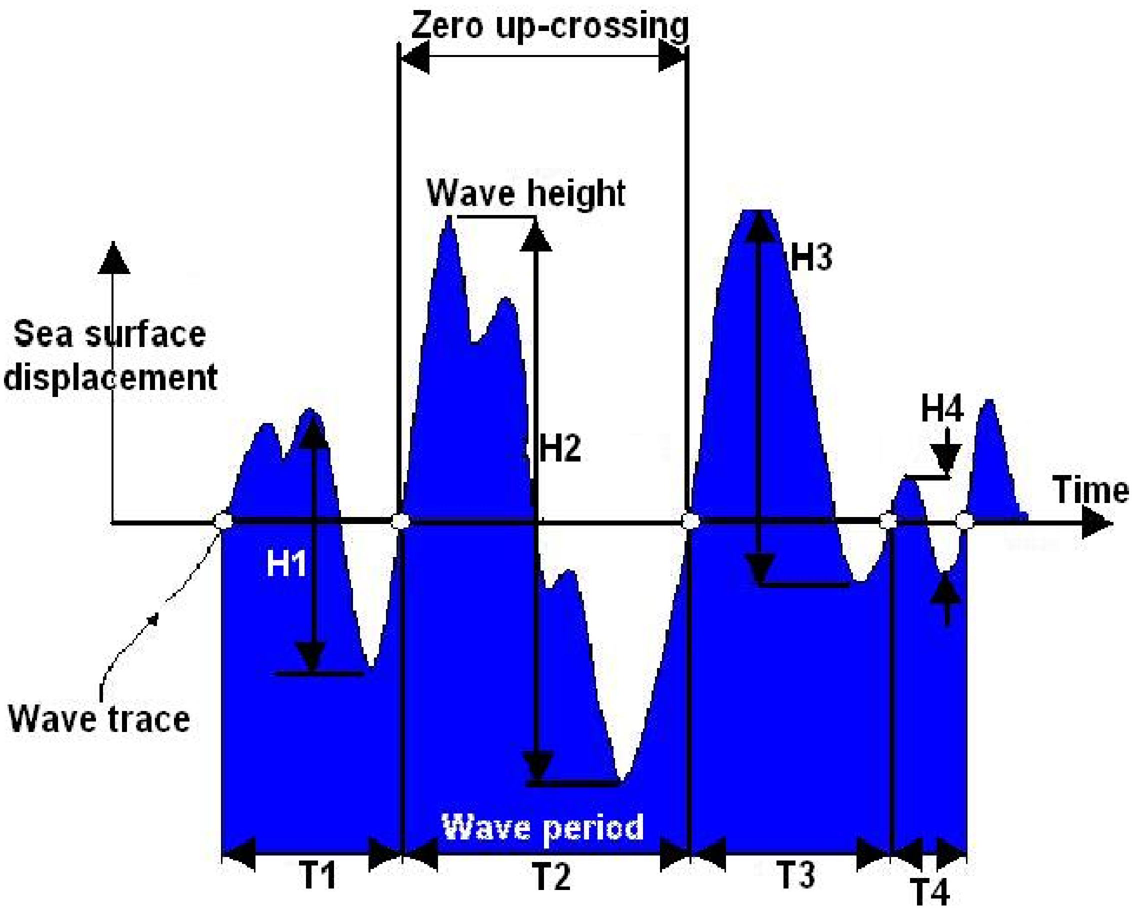
9 Appendix A Zero up-crossing analysis

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.



10 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.