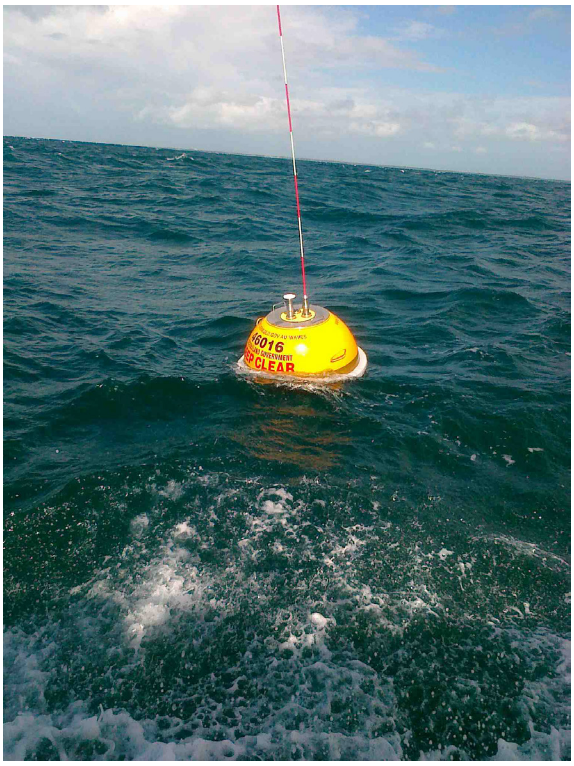
Department of Science, Information Technology and Innovation



Queensland Wave Climate

Wave Monitoring Annual Summary

November 2013 to October 2014

Coastal Impacts Unit, DSITI

Queensland Government

Prepared by

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Daryl Metters, Robert Wall and Paul Boswood

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Executive Summary

This summary of wave climate in Queensland is 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 2013 to 31 October 2014.

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.

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 and the type of analyses employed.

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 five tropical cyclones that moved close to the Queensland coast during the reporting period. Tropical cyclones Ita, Dylan and Gillian made landfall on the coast, while Edna and Hadi briefly passed close to the central Queensland coast.

Tropical cyclone (TC) Ita made landfall as a category 5 severe tropical cyclone on 11 April (DSITIA, 2014). After decaying to a tropical low pressure system Ex-Tropical Cyclone Ita continued south easterly inland of the coast. Several top ten wave heights were reported, with a number one record of 3.4 m Hsig and 5.6 m Hmax at Cairns. Ex-TC Ita left the coast north of Mackay.

Tropical cyclone Dylan made landfall on 31 January 2014 near Bowen as a category 2 tropical cyclone. A record Hsig of 5.0 m ranked second while a Hmax of 10 m ranked the top Hmax at Mackay. This record is impressive considering the 40 years of wave buoy operation at Mackay.

Tropical cyclone Gillian meandered around the Gulf of Carpentaria and briefly crossed the west coast of Cape York Peninsular. A record Hsig of 2.1 m and Hmax of 3.9 m ranked the ninth top wave recorded at Albatross Bay Weipa.

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 2013 to 31 October 2014.

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

The Department of Science, Information Technology and Innovation, as part of its long-term data collection program, 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 2013 – October 2014

Long-term	Joint project	Joint project partners
Brisbane	Tweed Heads	TRESBP *
Emu Park	Gold Coast	Gold Coast City Council
Mackay	Caloundra	Port of Brisbane Corporation
Townsville	North Moreton	Port of Brisbane Corporation
Cairns	Mooloolaba	Department of Transport
	Gladstone	Gladstone Ports Corporation

	Hay Point	North Queensland Bulk Ports
	Abbot Point	North Queensland Bulk Ports
	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

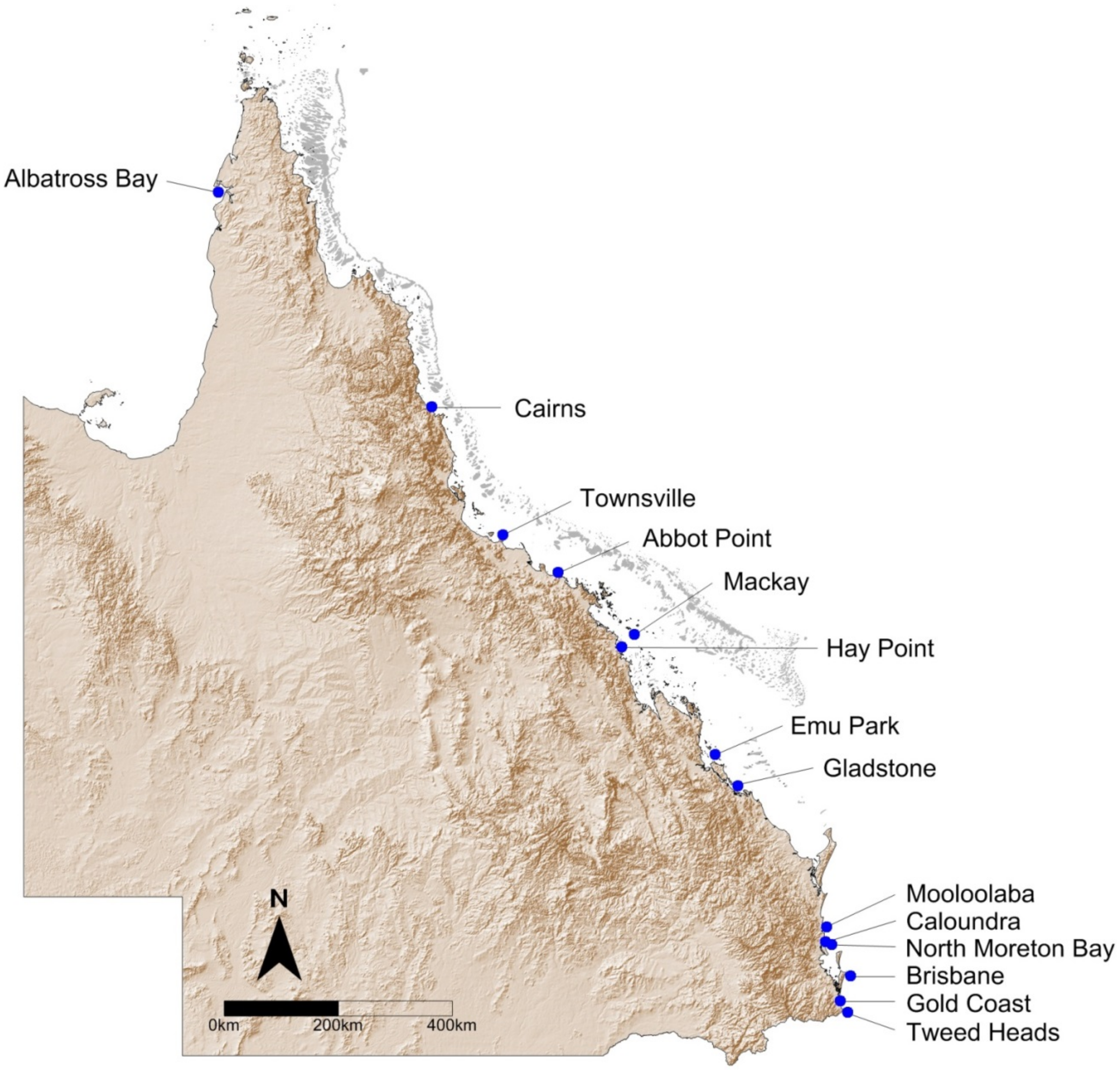


Figure 1 DSITI wave monitoring sites in Queensland

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	19.8	19.8
Gold Coast	21/03/1987	-	-	17/07/2007	27.7	7.3
Brisbane	31/10/1976	-	-	20/01/1997	38.0	17.8
Caloundra	01/05/2013	-	-	01/05/2013	1.5	1.5
North Moreton Bay	08/03/2010	-	-	08/03/2010	4.7	4.7
Mooloolaba	20/04/2000	-	-	11/05/2005	14.5	9.5
Gladstone	23/09/2009	-	-	23/09/2009	5.1	5.1
Emu Park	24/07/1996		-	24/07/1996	18.3	18.3
Hay Point	24/04/1977	25/05/1987	3/04/1993	31/10/2009	31.7	5.0
Mackay	19/09/1975	-	-	13/03/2002	39.1	12.6
Abbot Point	17/01/2012	-	-	17/01/2012	2.8	2.8
Townsville	20/11/1975		-	29/10/2008	39.1	6.0
Cairns	04/05/1975	-	-	-	39.5	0.0
Albatross Bay (Weipa)	22/12/1978	-	-	25/11/2008	35.9	5.9

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, Central Moreton Bay, 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.

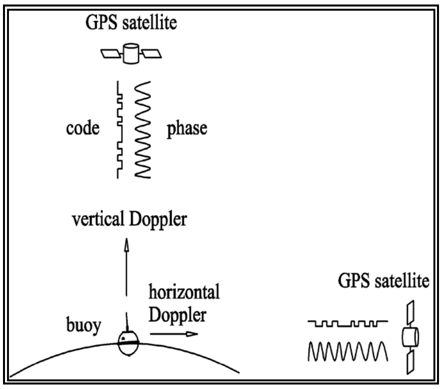


Figure 2 The GPS wave measurement principle (Datawell, 2010)

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 (1.28Hz) and stored in bursts of 2048 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 also after recovery. Normally, a buoy is calibrated every 12 months. Calibration of accelerometer buoys is performed at DSITI’s Deagon site using a buoy calibrator to simulate sinusoidal waves with vertical displacements of 2.7 metres. It is usual to check three frequencies between 0.016–0.25Hz 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 buoy 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 no 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 0.01Hz. 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 º True)
SST	Sea surface temperature (in º 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. Before any use is made of this data, the exact location of the buoy, and the water depth in which the buoy was moored, should be noted.

6 Major Meteorological events

Table 4 Tropical Cyclones in the Queensland region during the 2013–2014 season

Name	Start Date	End Date	Category	Central Pressure (hPa)
Dylan	29/01/2014	31/01/2014	2	975
Edna	01/02/2014	07/02/2014	1	985
Gillian	08/03/2014	25/03/2014	1	996
Hadi	10/03/2014	11/03/2014	1	992
Ita	04/04/2014	14/04/2014	5	930

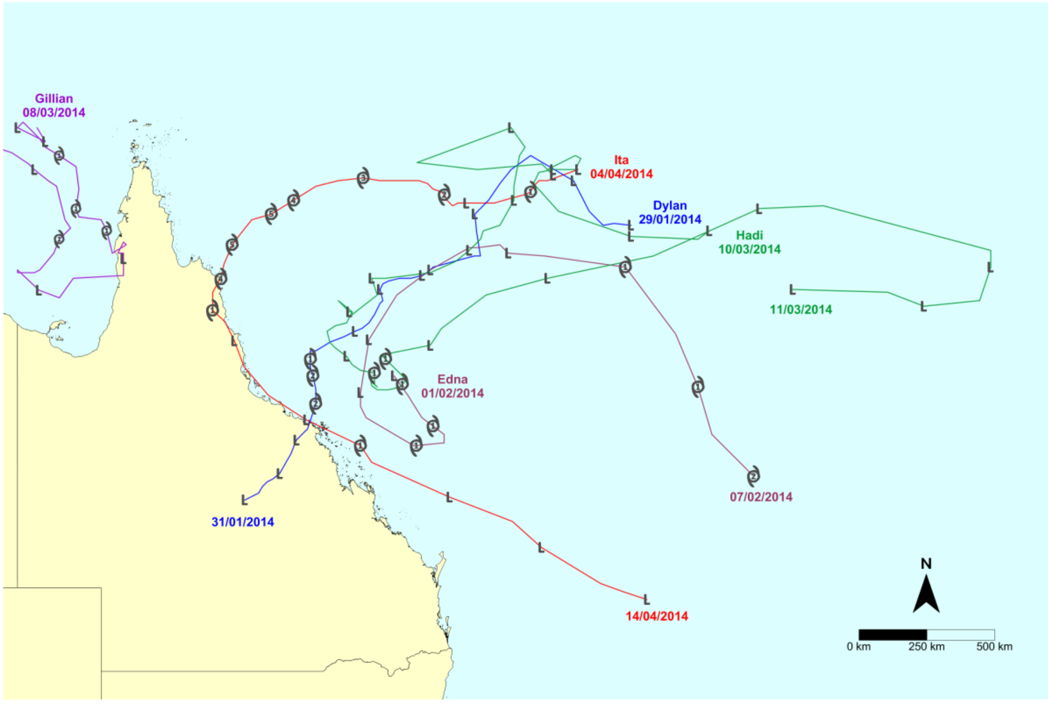


Figure 3 Tropical cyclones affecting Queensland coastline 2013–14

7 Queensland wave climate

7.1 Tweed Heads

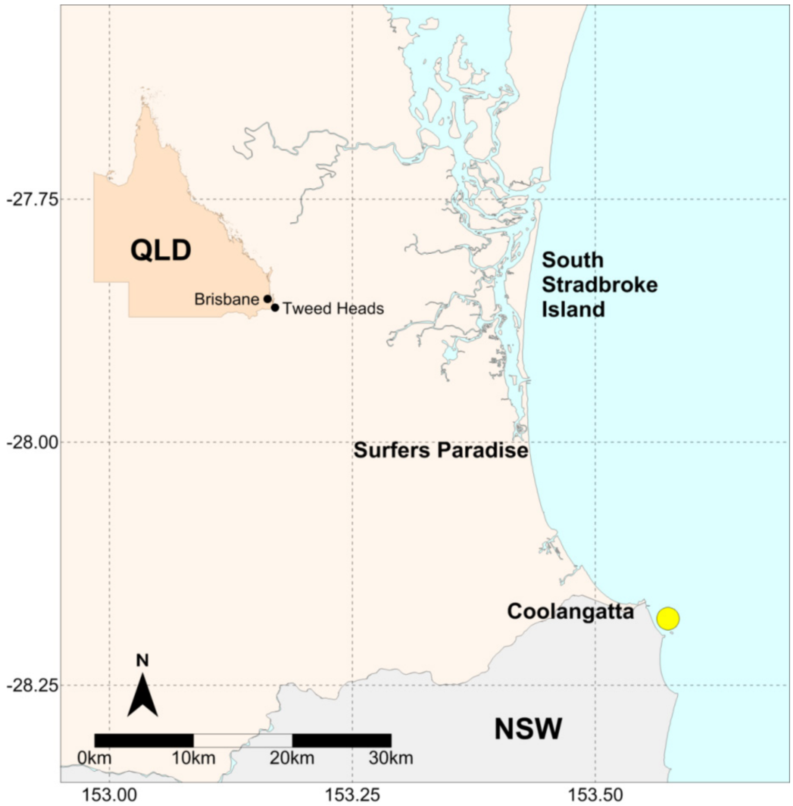


Figure 4 Tweed Heads – Locality plan

Table 5 Tweed Heads – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	13/01/1995	0.3 years	290,927	19.8
2013 -14	1/11/2013	8.73 days	17,100	1

Table 6 Tweed Heads – Buoy deployments during the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
28°10.890'S	153°34.607'E	22	08/02/2013	21/01/2014
28°10.910'S	153°34.555'E	22	21/01/2014	17/04/2014
28°10.870'S	153°34.485'E	20	17/04/2014	current

7.1.1 Tweed Heads – seasonal overview

The Tweed Heads wave buoy has been operational for nearly 20 years with an overall data return of 98.5 percent. The data record for the period November 2013 to October 2014 was very good, with total gaps of only 8.73 days, equivalent to 97.6 percent data return. The buoy was replaced during the reporting period on 21 January 2014 (Table 6).

Ex-TC Lusi persisted as a low pressure system off the north coast of New Zealand in March 2014 Significant wave height of 3.4 m continued over a 3 hour period while maximum wave height of 5.5 m was recorded by the Tweed Heads buoy (Table 8). Large waves were also seen in August through the passage of east coast lows across south east Australia.

There are differences in the wave climate off Tweed Heads between summer and winter seasons. Over 4 percent of the time Hsig exceeded 2.0m during summer whereas during winter Hsig exceeded 2.0 m only 2.5 percent of the time (Figure 8). The most common Tp is 10 seconds in summer and 8 seconds in winter (Figure 10).

The wave height during the reporting period was generally lower than the wave height of the whole record, evidenced in the percentage exceedance (Figure 8) and during summer in the histogram of the occurrence of Hsig (Figure 9). Wave period Tp (Figure 10) was longer in winter than in summer.

It is also worth noting that the ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data; these are plotted in Figure 11. The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean with the exception of two months: February and August. In February the mean was higher than the mean +1 sd, possibly influenced by the passage of Ex-TC Oswald, see Figure 7.

The plot of wave direction over the 2012–13 season (Figure 6) showed a dominant easterly (slightly south of east) direction with an occasional swing to the north, mostly during summer. The dominance of incident wave direction is reflected in the directional wave rose plot (Figure 12) along with the most common wave height (Hsig) of 1.0 m to 1.5 metres.

The temperature (sea surface temperature, SST) measured in the buoy hull showed a seasonal high average around 27 °C with peaks of over 30 °C in summer (Figure 6). The SST from January and February was intermittently warm enough for tropical cyclone development, however the data up to February 08 is erroneous as calibration of the SST sensor post retrieval showed that the sensor was potentially measuring up to 7 degrees too low.

Table 7 Tweed Heads – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	3/05/1996 1:00	7.5	2/05/1996 14:30	13.1
2	28/01/2013 8:30	6.7	28/01/2013 9:00	11.8
3	6/03/2004 1:00	6.1	5/03/2004 23:30	11.1

4	21/05/2009 19:30	5.6	30/06/2005 6:30	9.9
5	24/05/1999 5:00	5.2	22/05/2009 7:00	9.7
6	4/03/2006 20:30	5.2	4/03/2006 12:00	9.6
7	12/06/2012 10:00	5.2	25/03/1998 22:30	9.5
8	15/02/1995 11:30	5.2	15/02/1995 15:30	9.3
9	30/06/2005 9:00	4.9	12/06/2012 11:30	9.3
10	24/03/2004 6:00	4.8	2/02/2001 2:00	9.1

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
16/03/2014 01:00	3.4 (3.7)	5.5 (6.3)	14.9	Ex-TC Lusi weakened into a complex low and persisted from 14–16 March just north of New Zealand's North Island in the Tasman Sea.
28/08/2014 10:30	3.2 (3.5)	5.1 (6.3)	12.4	An east coast low pressure system with a central pressure of 1011 hPa
28/03/2014 07:00	2.9 (3.1)	4.8 (5.7)	8.1	A large high pressure system located in the eastern Tasman Sea developed strong onshore flow on the east coast of Queensland and northern NSW.
17/08/2014 02:00	2.5 (2.7)	4.0 (4.6)	7.5	An east coast low pressure system with a central pressure of 998 hPa

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.

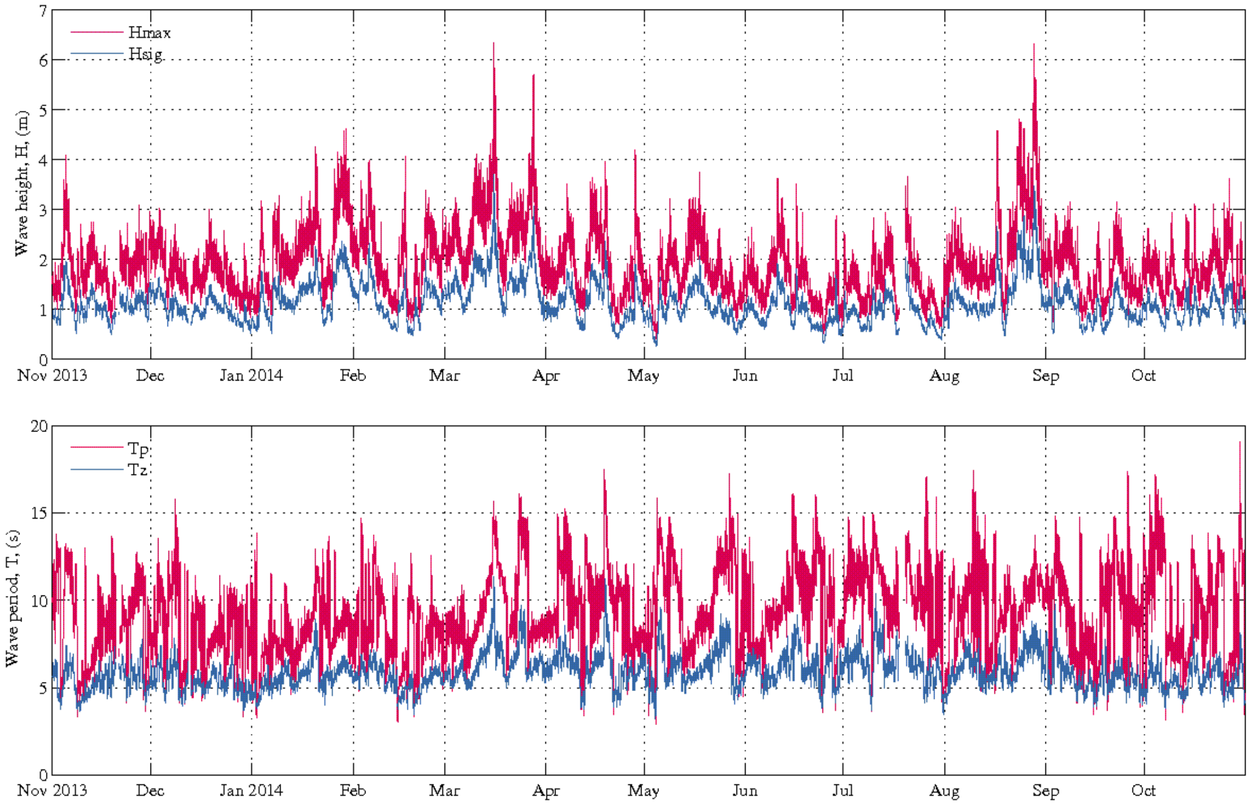


Figure 5 Tweed Heads – Daily wave recordings

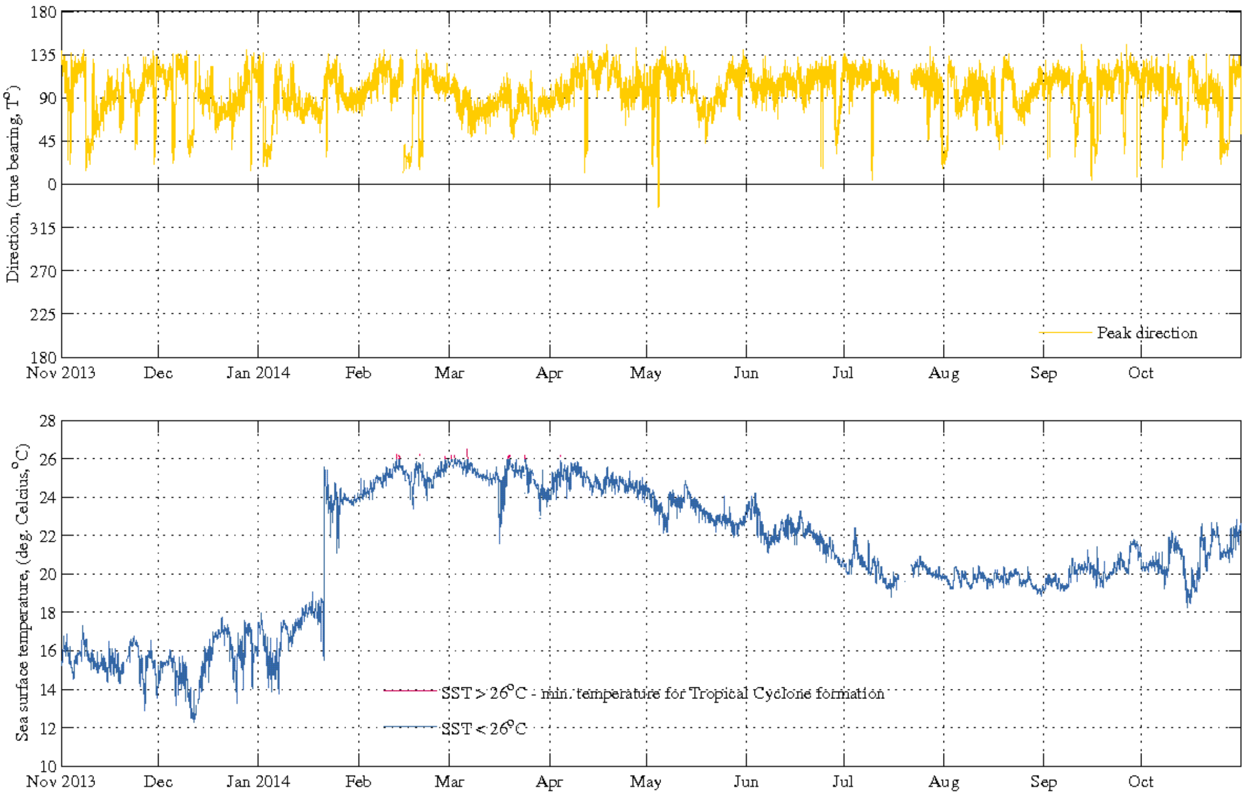


Figure 6 Tweed Heads – Sea surface temperature and peak wave directions

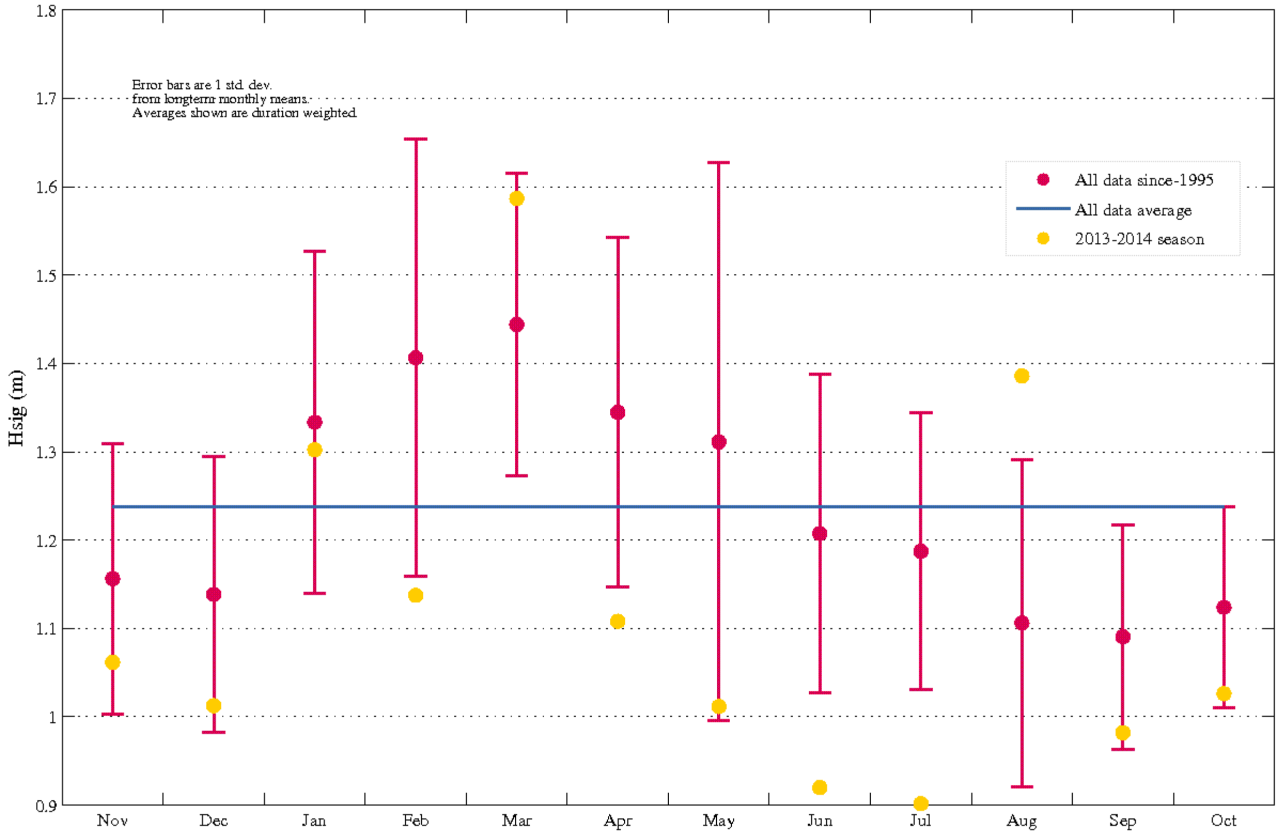


Figure 7 Tweed Heads – Monthly average wave height (Hsig) for seasonal year and for all data

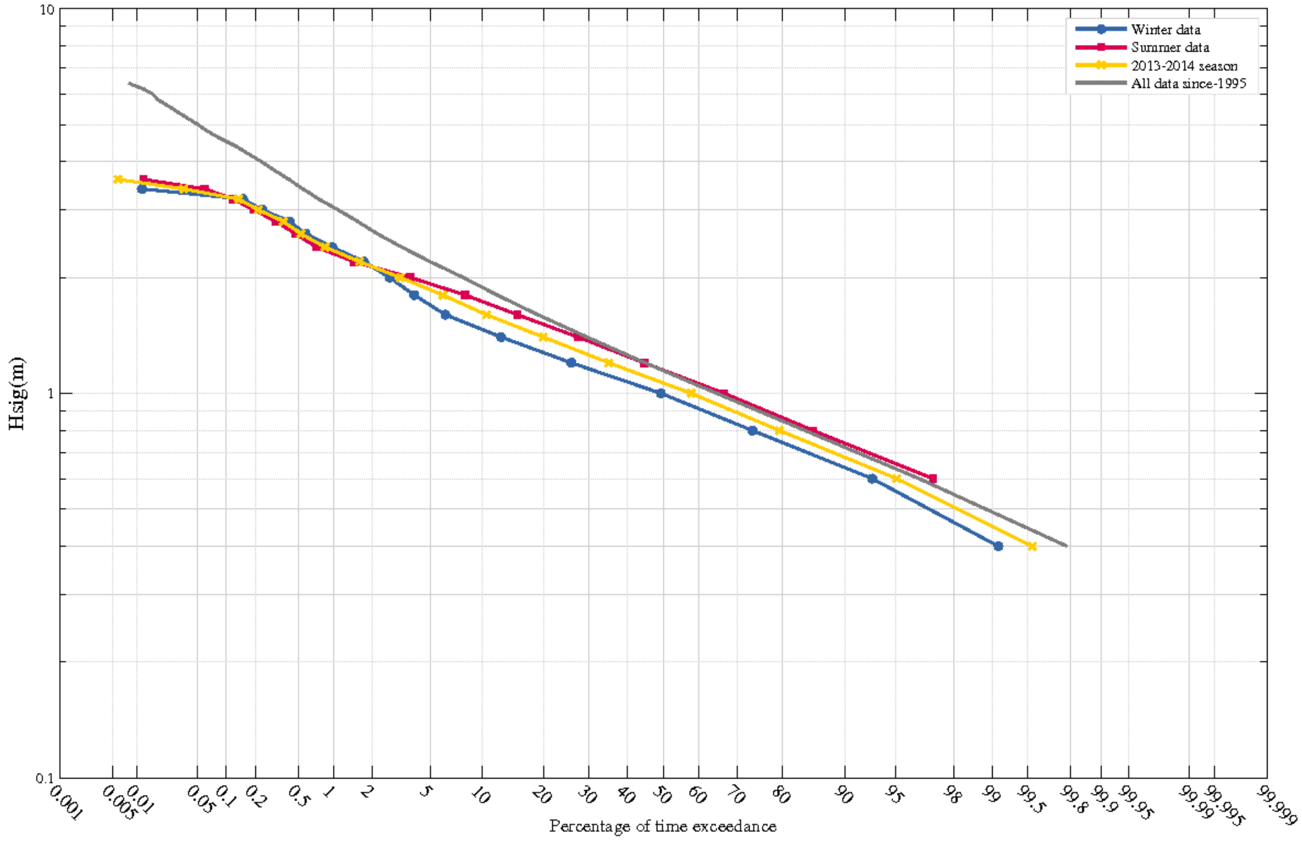


Figure 8 Tweed Heads – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

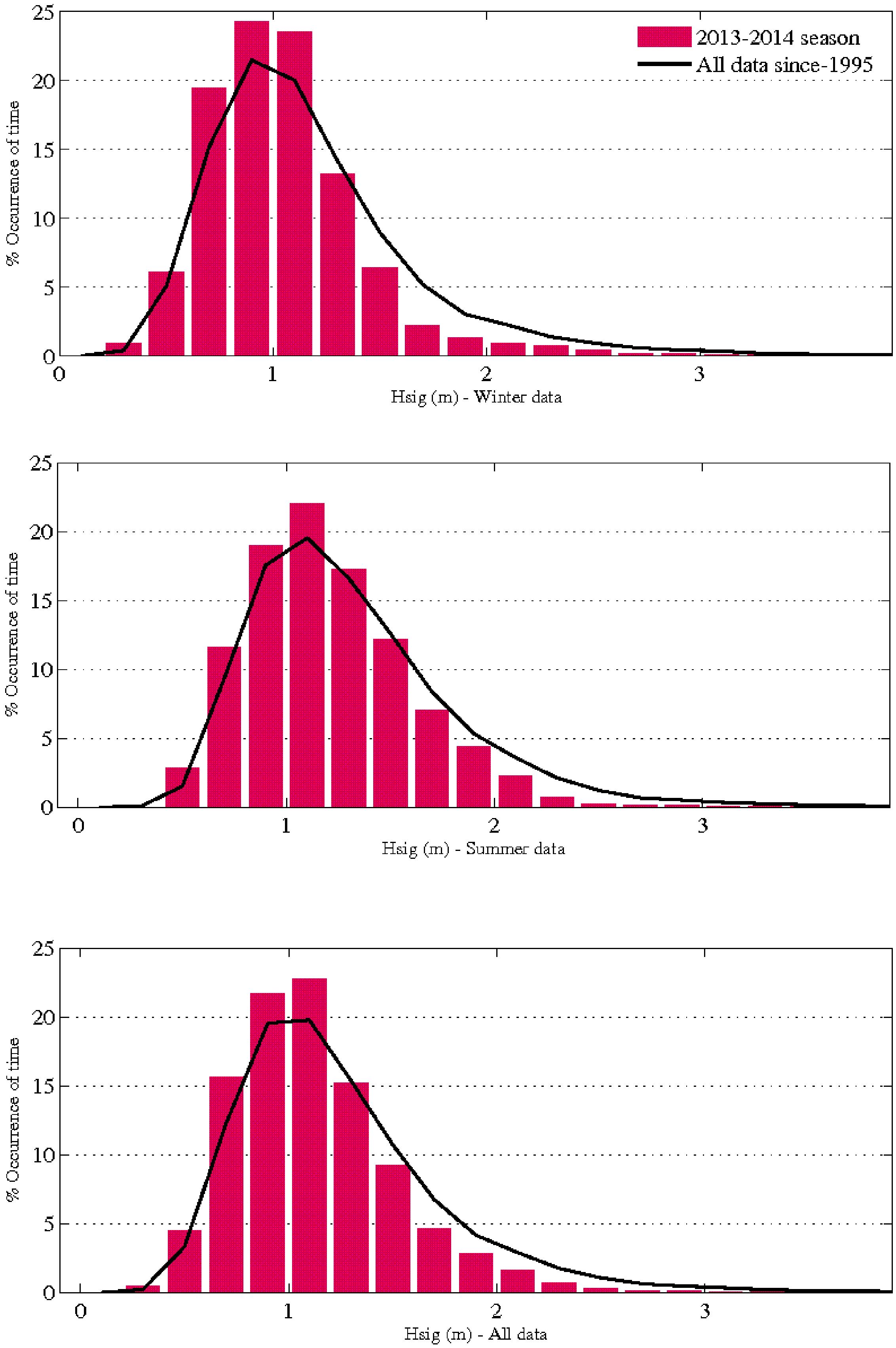


Figure 9 Tweed Heads – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

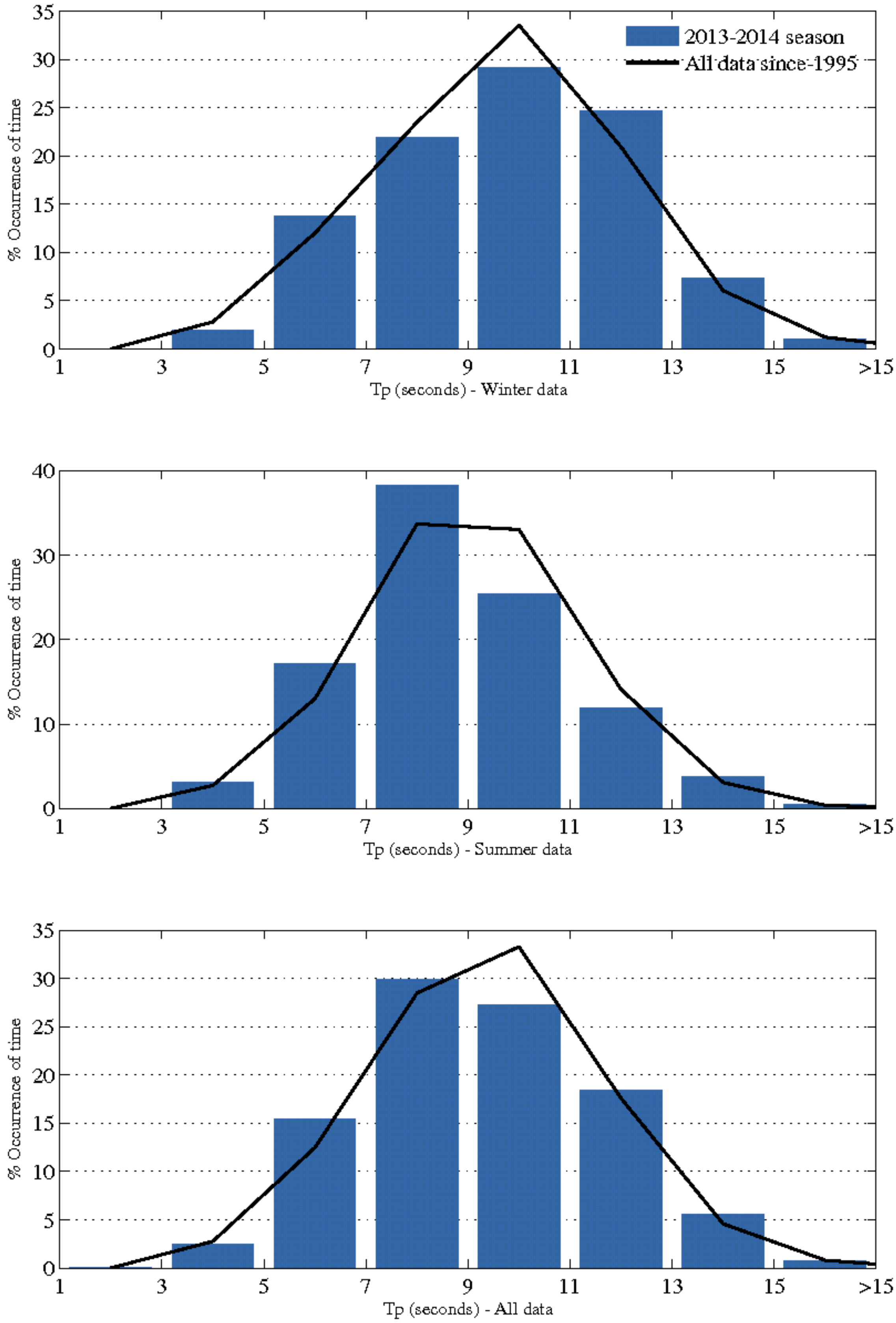


Figure 10 Tweed Heads – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

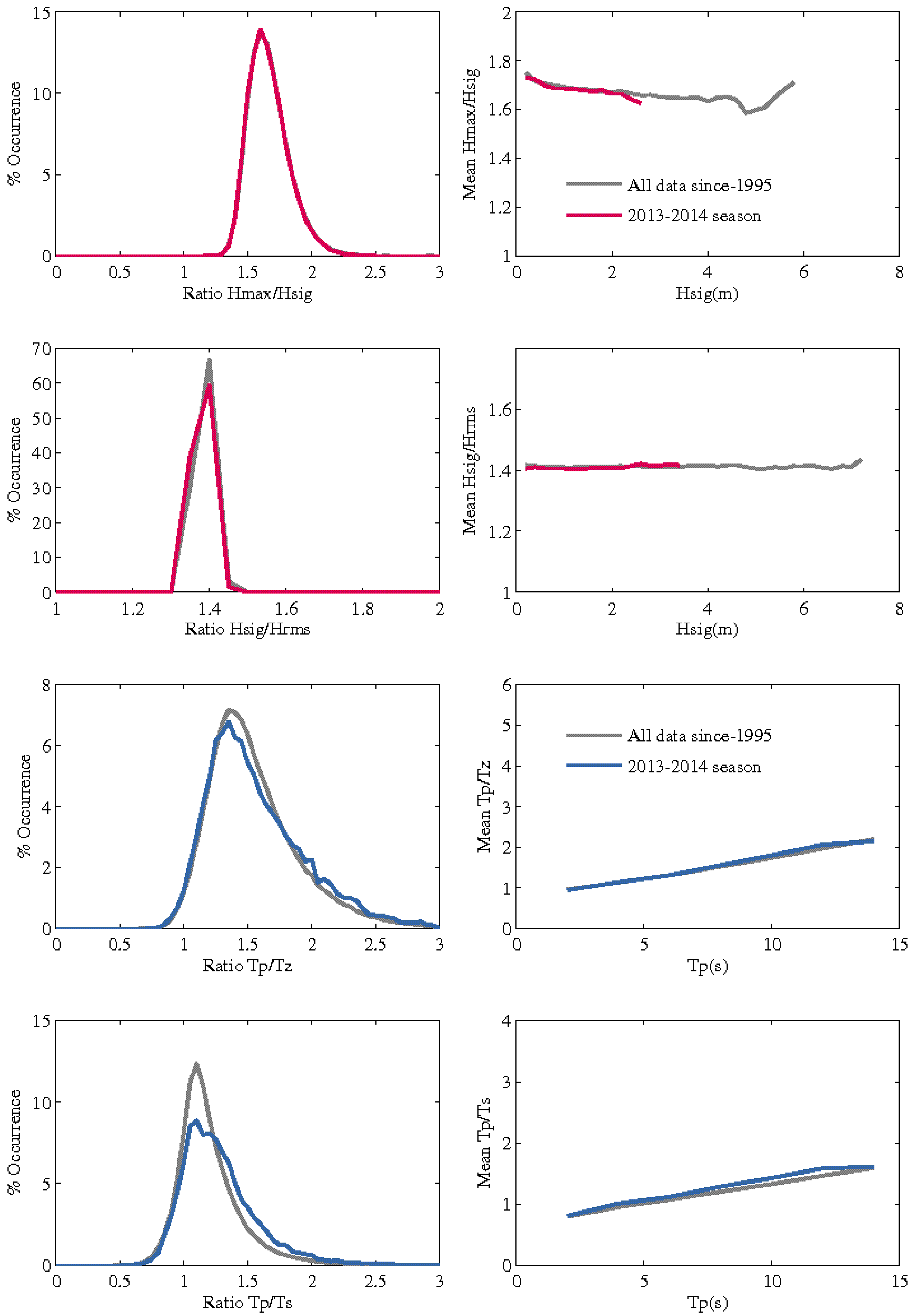


Figure 11 Tweed Heads – Wave parameter relationships

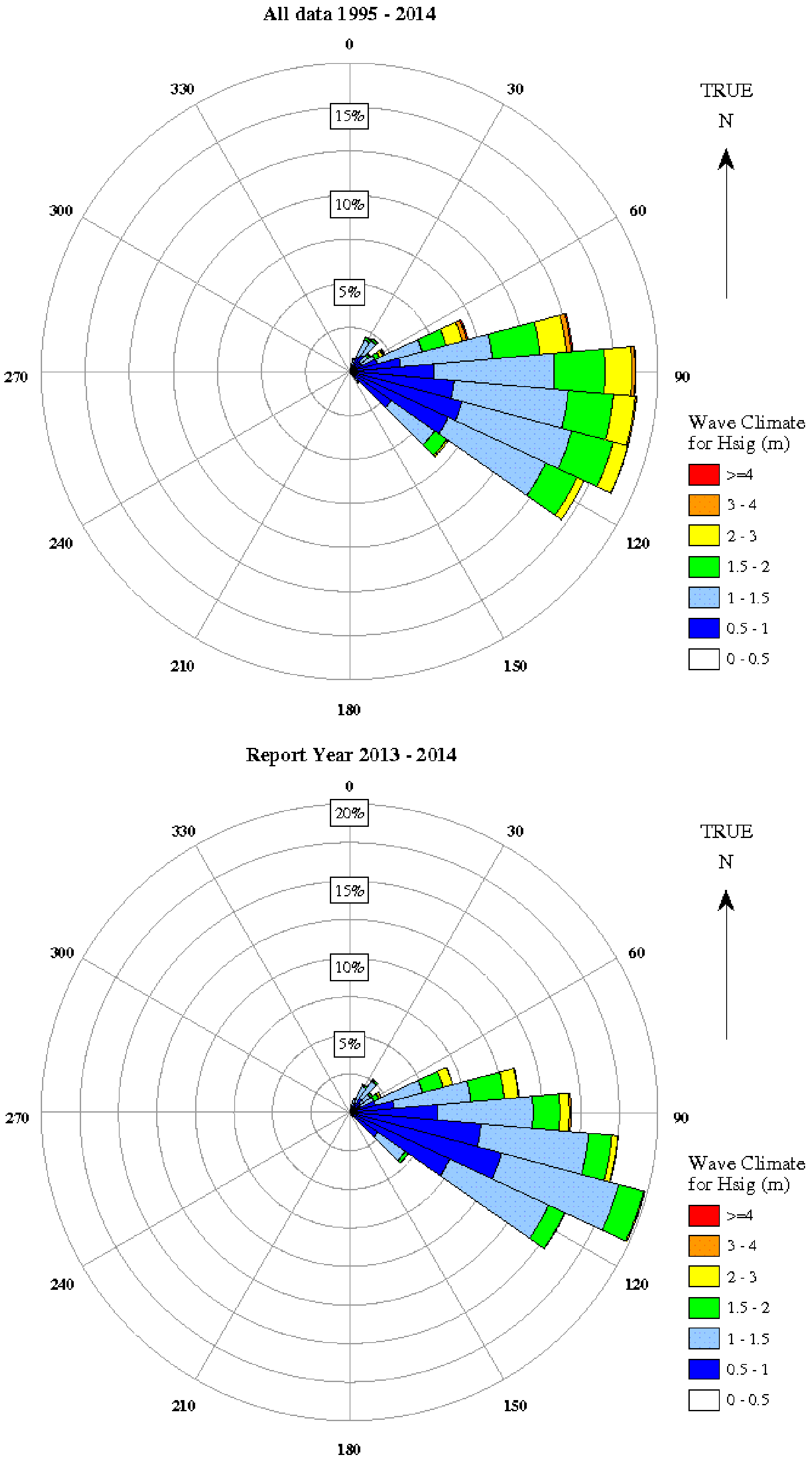


Figure 12 Tweed Heads – Directional wave rose

7.2 Gold Coast

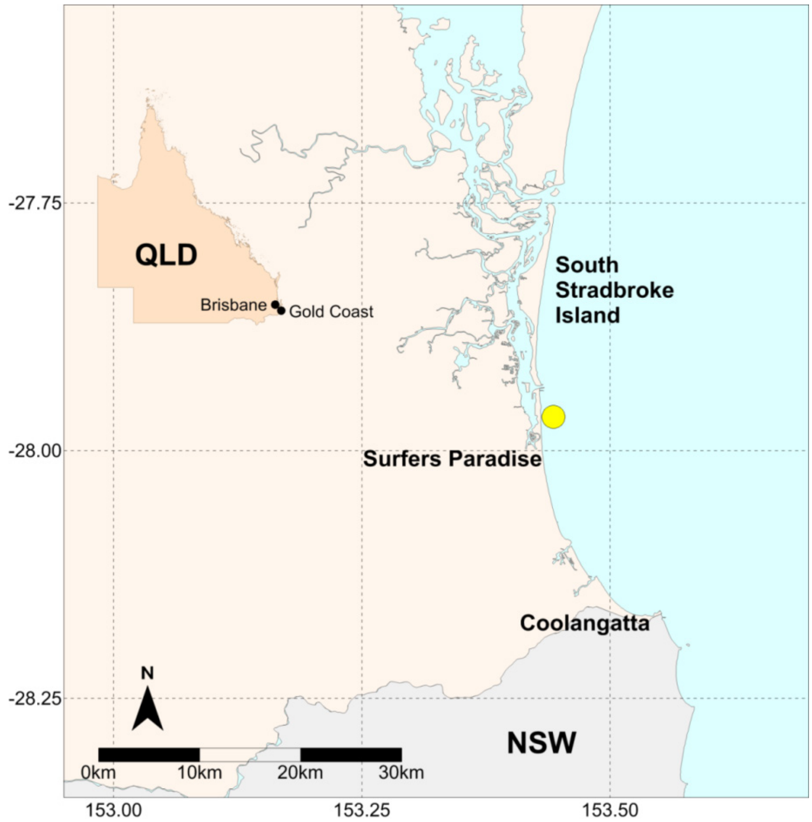


Figure 13 Gold Coast – Locality plan

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	320,653	27.7
2013–14	1/11/2013	0.6 days	17,490	1

Table 10 Gold Coast – Buoy deployments during the 2013-14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
27°57.914'S	153°26.555'E	17	15/02/2013	04/10/2014
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 27 years with an overall data return of 82.9 percent. The data record for the period November 2013 to October 2014 was exceptional, with total gaps of only 0.6 days, equivalent to 99.8 percent data return. The buoy was replaced once during the reporting period on 04 October 2014 (Table 10).

There were no waves recorded during the reporting period that ranked in the top 10 highest waves for the Gold Coast (Table 11). The largest significant wave height (Hsig) and maximum wave height (Hmax) of 3.6 m and 7.6 m for the period occurred on 28 August 2014from a low pressure system located off the east coast (Table 12). The large wave height seen in the time series for daily wave recordings (Figure 14) was a recording error and is omitted from the statistical calculations.

Time series of peak wave direction (Figure 15) show the predominant wave direction to from east to east-south-east. This is also seen in the directional wave rose (Figure 21) and shows similar wave directions for the reporting period and the entire record.

The monthly average Hsig (Figure 17) fell within one standard deviation (sd) of the long-term mean except for June, July and August. Monthly average Hsig from April to July was consistently below the record mean, on the bounds of 1 sd in April and May, and exceeding 1 sd in June and July. The monthly average for August was much greater than +1 sd which is when the largest waves were recorded for the period.

The histograms of percentage occurrence of Hsig (Figure 18) shows similar distribution between summer and winter and between the reporting period and the entire record. The most frequently occurring Hsig ranged from 0.8–1.0 m. Histograms of percent occurrence of Tp (Figure 19) show 7–9 second waves 40 percent of the time during summer, where this was more evenly spread from 7–13 seconds during winter. The occurrence of 9–11 second waves in the overall reporting period was less than the entire record however generally the wave distribution was similar to the entire record.

Table 11 Gold Coast – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	3/05/1996 6:30	7.1	3/05/1996 6:30	12.0
2	28/01/2013 10:30	6.3	17/03/1993 4:30	11.0
3	23/05/2009 3:30	6.1	5/03/2006 5:00	10.7
4	5/03/2004 23:00	5.9	22/05/2009 12:30	10.6
5	17/03/1993 12:30	5.7	5/03/2004 22:00	10.6
6	25/04/1989 21:00	5.6	12/06/2012 7:00	10.5
7	12/06/2012 7:00	5.5	28/01/2013 9:30	10.5

8	5/03/2006 8:00	5.3	25/04/1989 9:30	10.0
9	15/02/1995 7:00	5.0	15/02/1995 10:30	9.2
10	2/04/2009 5:30	4.9	2/04/2009 5:30	9.0

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
16/03/2014 05:00	3.1 (3.6)	5.2 (6.7)	14.5	Ex-TC Lusi weakened into a complex low and persisted from 14–16 March just north of New Zealand's North Island in the Tasman Sea.
23/08/2014 14:30	2.7 (2.9)	4.5 (5.1)	9.1	An east coast low pressure trough with a central pressure of 1017 hPa
28/08/2014 12:30	3.3 (3.6)	5.7 (7.6)	12.2	An east coast low pressure system with a central pressure of 1011 hPa

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.

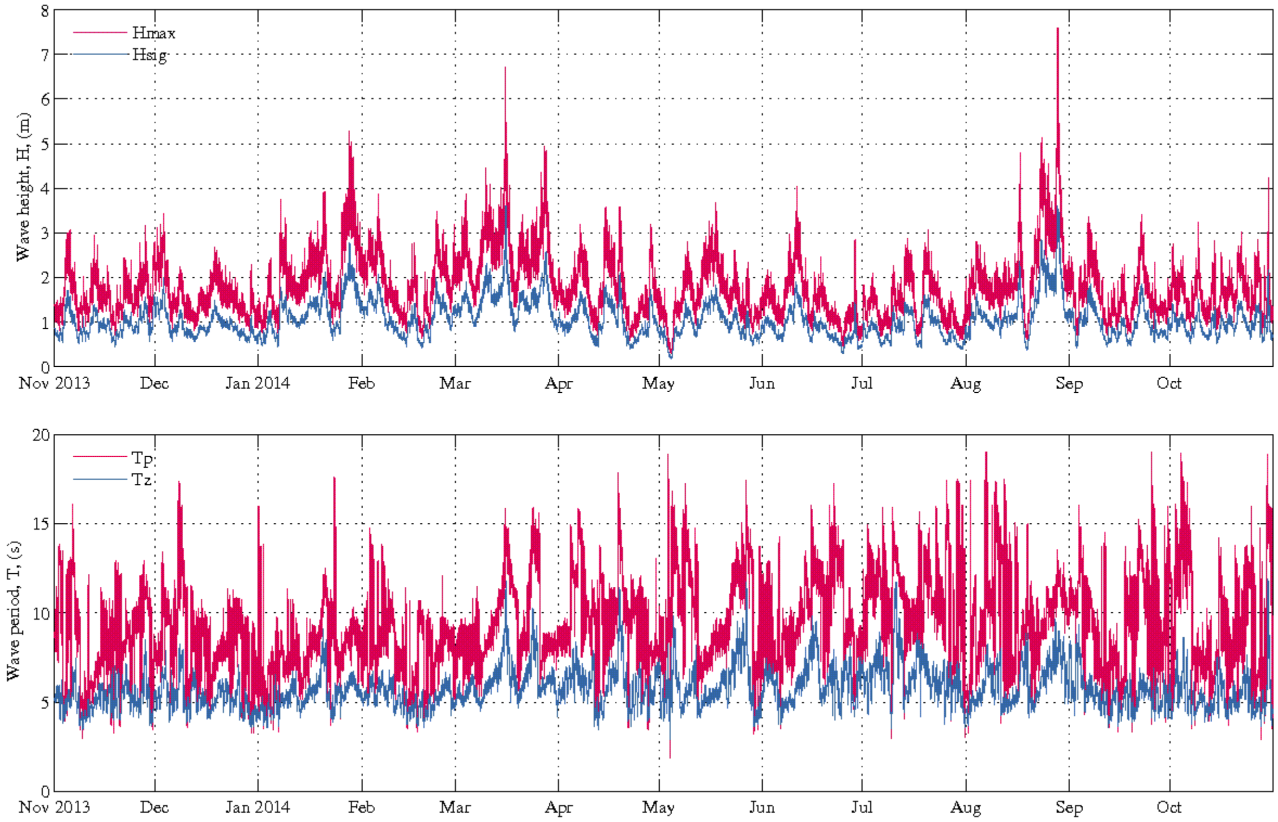


Figure 14 Gold Coast – Daily wave recordings

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

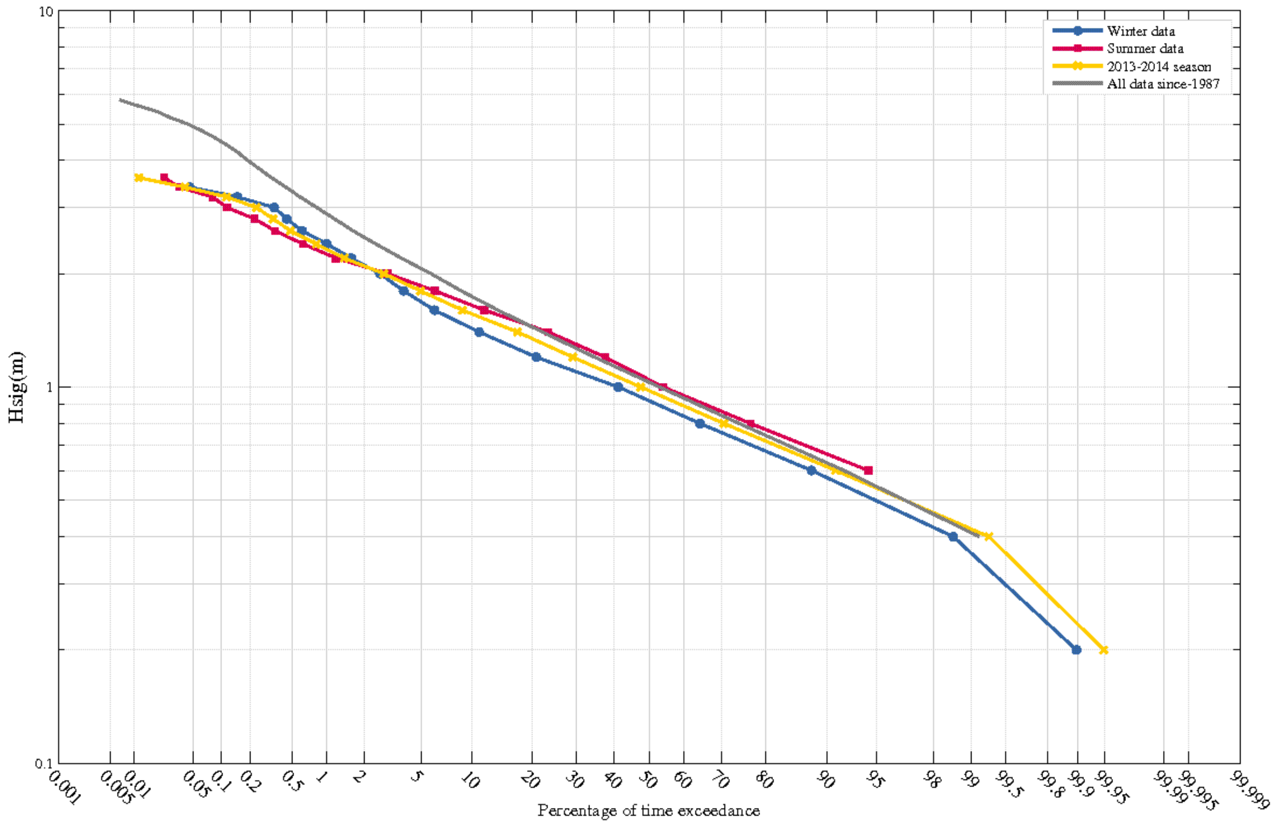


Figure 16 Gold Coast – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

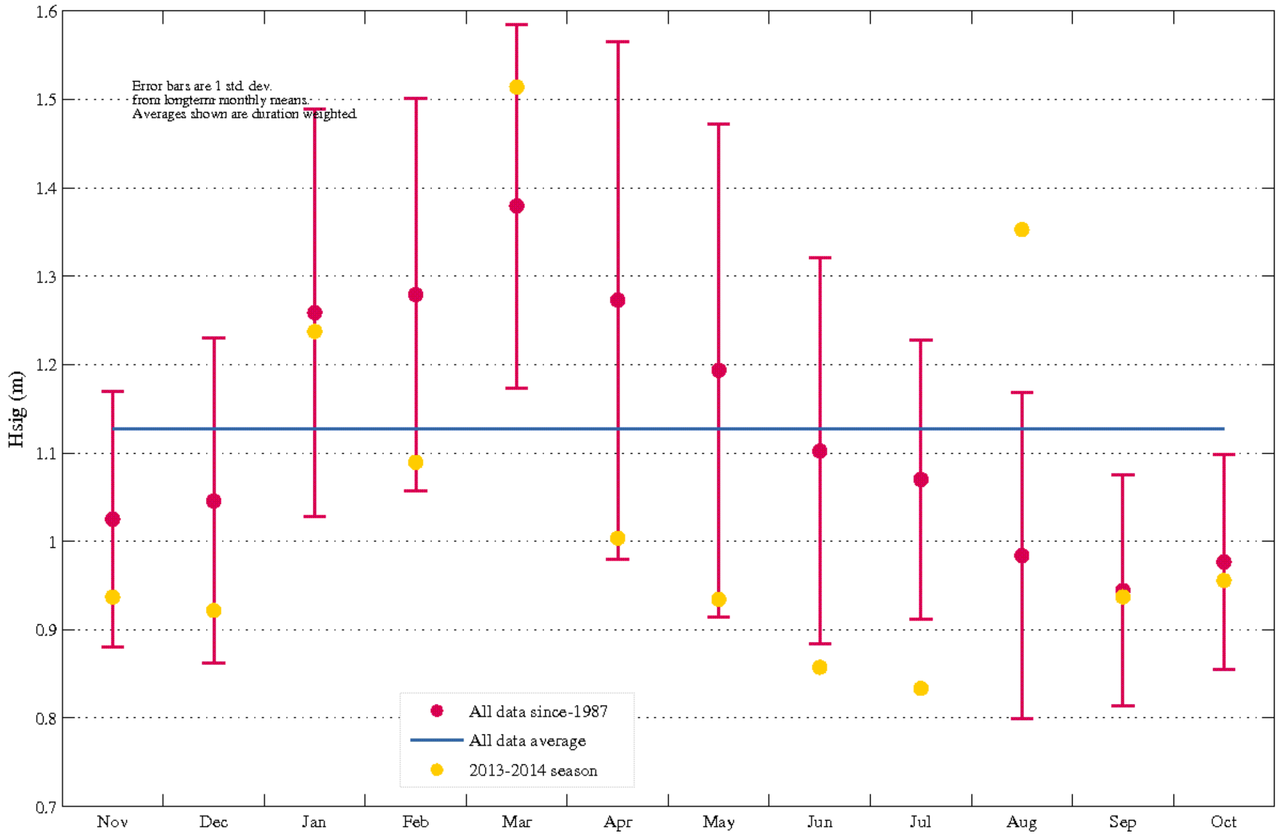


Figure 17 Gold Coast – Monthly average wave height (Hsig) for seasonal year and for all data

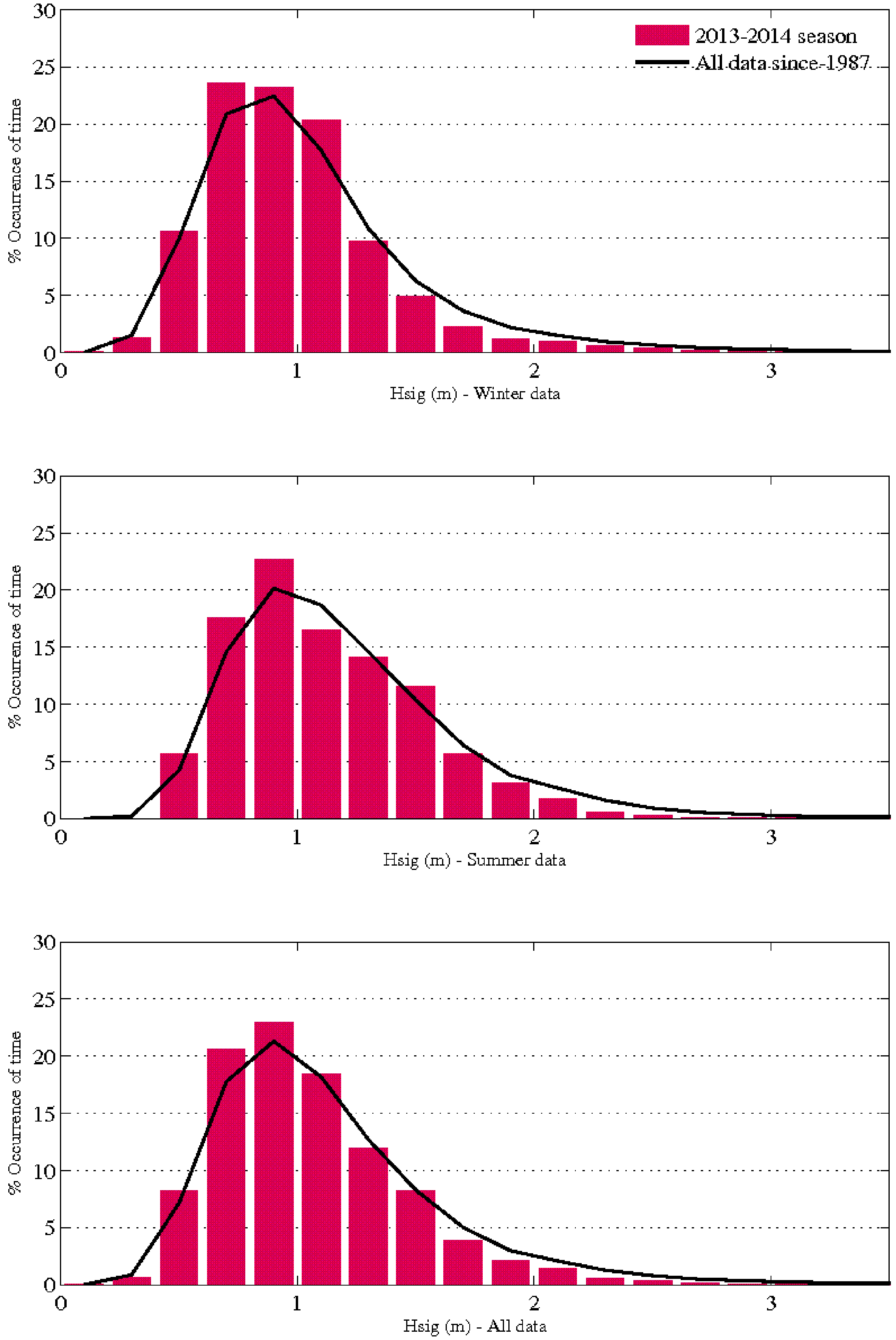


Figure 18 Gold Coast – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

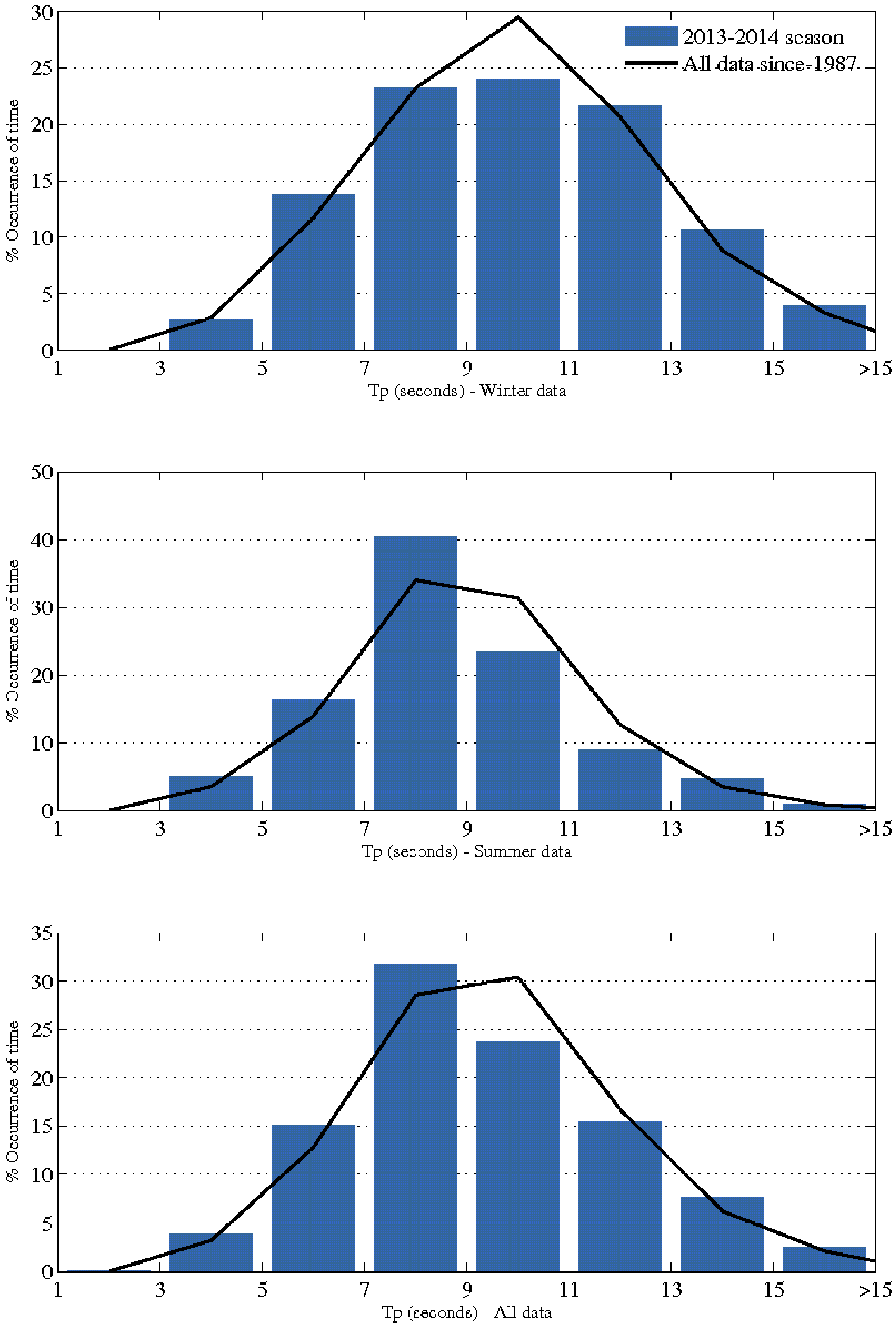


Figure 19 Gold Coast – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

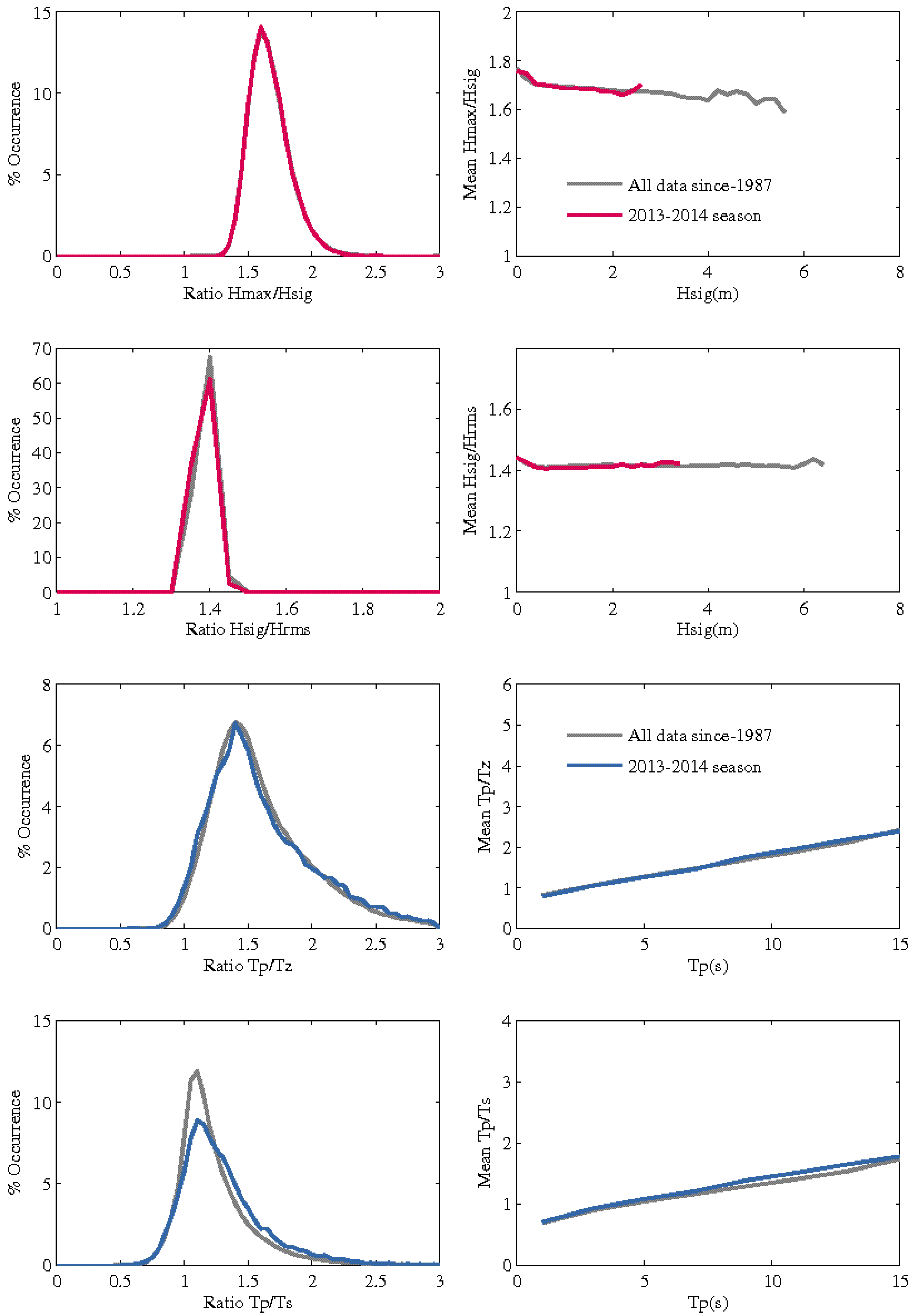
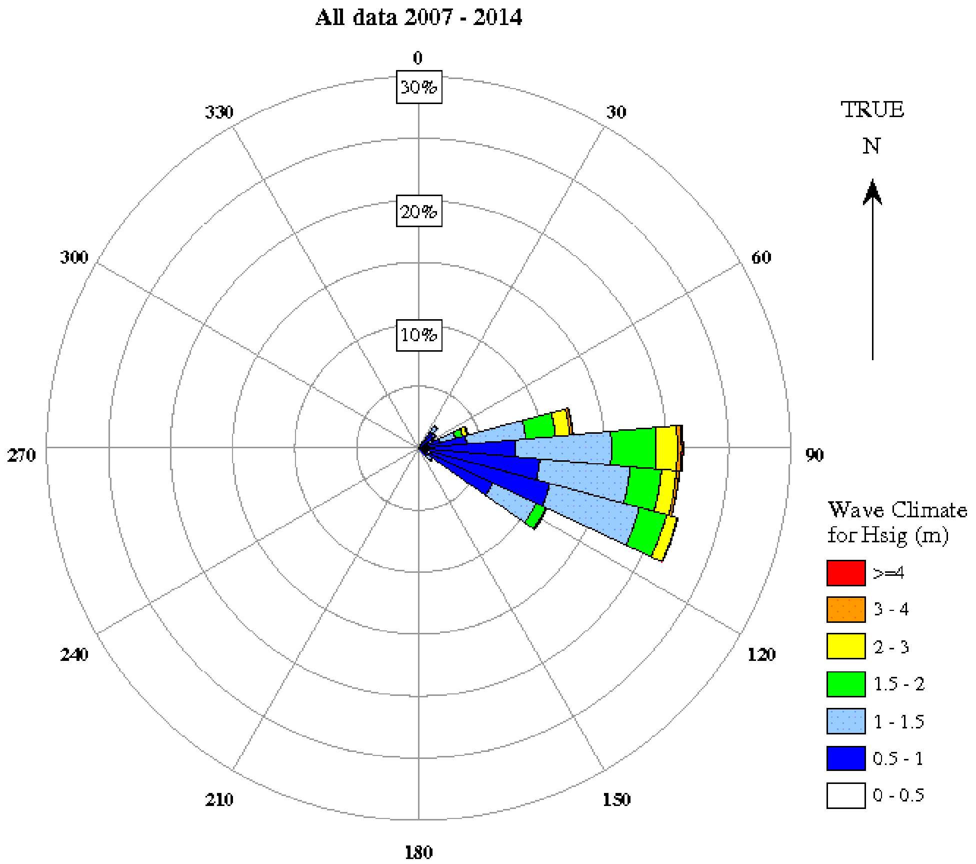


Figure 20 Gold Coast – Wave parameter relationships



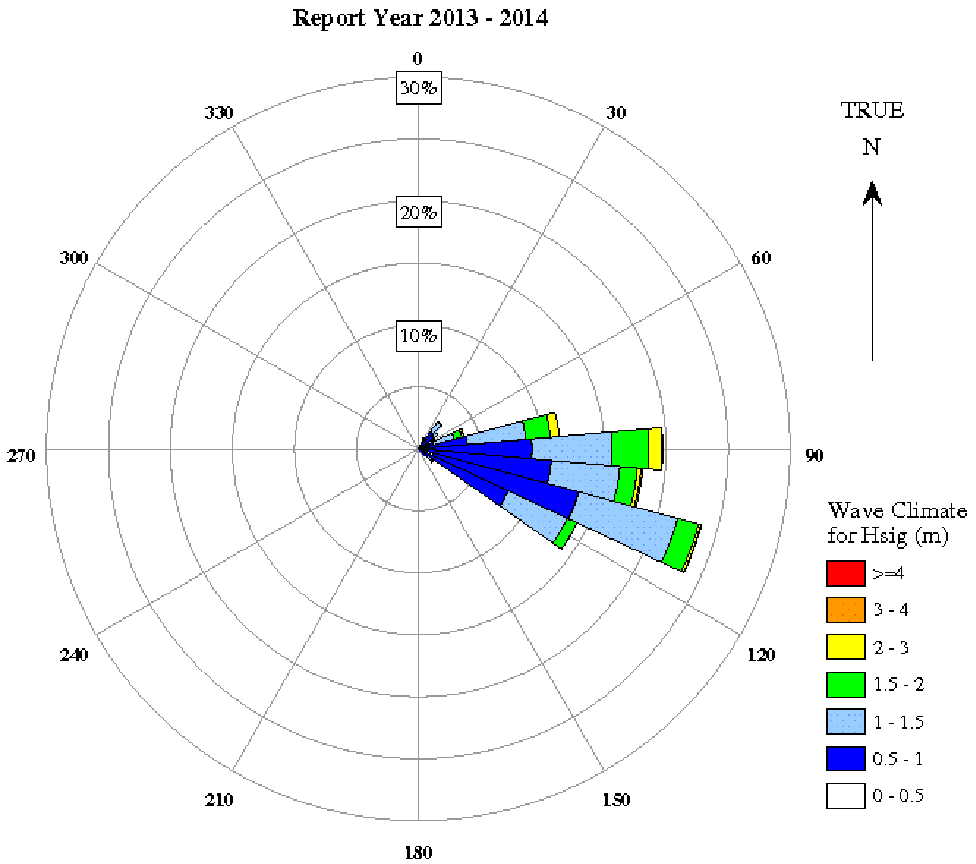


Figure 21 Gold Coast – Directional wave rose

7.3 Brisbane

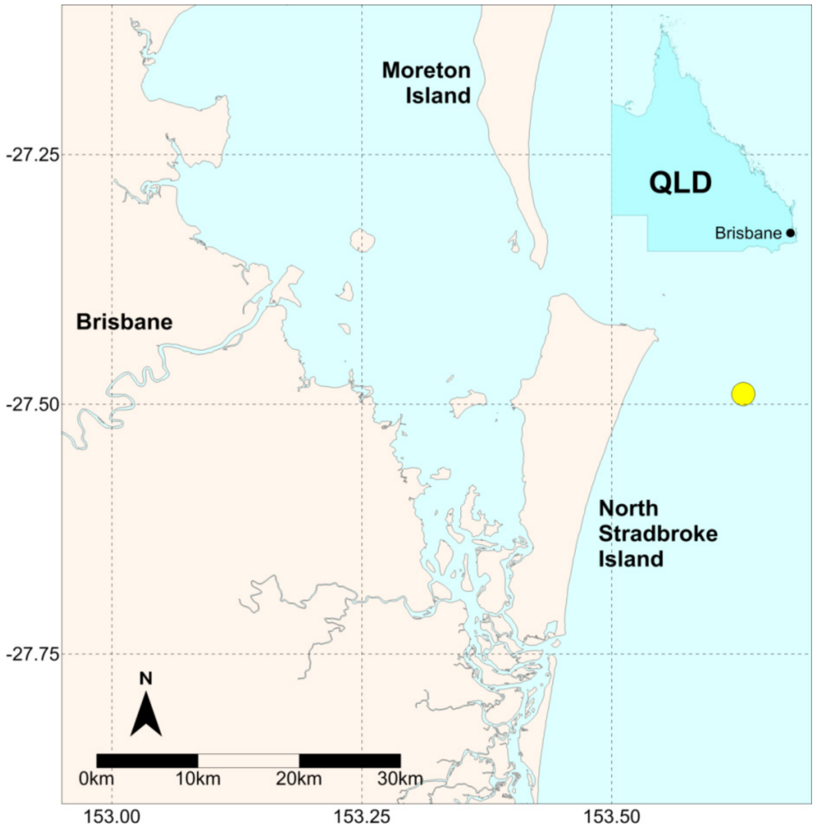


Figure 22 Brisbane – Locality plan

Table 13 Brisbane – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/1976	11.71 years	319715	38
2013 -14	1/11/2013	17.2 days	16697	1

Table 14 Brisbane – Buoy deployments during the 2013-14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date	Reason for change
27°29.450'S	153°37.990'E	70	26/06/2013	04/02/2014	Normal change
27°29.400'S	153°37.630'E	70	04/02/2014	31/10/2014	Lost comms.
27°29.475'S	153°37.955'E	70	31/10/2014	current	Buoy broke free

7.3.1 Brisbane – seasonal overview

The Brisbane wave buoy has been operational for over 38 years. The data record for the period November 2013 to October 2014 was reasonable, with total gaps of 17.2 days, equivalent to a 95.3 percent data return. The buoy was replaced twice during the reporting period :– on 4 February 2014 due to transmission failure, and on 31 October due to the buoy breaking free of its mooring.

There were no record breaking waves during the reporting period that ranked in the top 10 highest waves for Brisbane (Table 15). The largest significant wave height (Hsig) and maximum wave height (Hmax) of 4.8 m and 8.9 m for the period occurred on 28 August 2014 from a combination of a low pressure system and coastal troughs present in south-east Queensland (Table 16). Time series for daily wave recordings (Figure 23) show a period of extended outage in later January and early February which led to the buoy being replaced.

Time series of peak wave direction (Figure 24) show a spread in wave direction from east to south. This spread is more obvious in the directional wave rose (Figure 30) with the most frequent wave direction being from the south-east. Wave directions for the reporting period are similar to the entire record.

The monthly average Hsig (Figure 25) generally fell within one standard deviation (sd) of the long term mean with an exception for June and August. During June the mean was outside of -1 sd and much greater than +1 sd in August. Higher wave heights in August can be attributed to the persistent low pressure system and coastal trough in south-east Queensland.

Percentage exceedance of Hsig (Figure 26) show very similar wave climates between summer and winter months as well as similar wave climates for the overall reporting period and the entire record. Histograms for occurrence of Hsig (Figure 27) also show very similar distributions between summer and winter and similarity between the reporting period and the whole record. The most frequent wave heights ranged from 1–1.4 m Hsig. Histograms for occurrence of peak wave period (Tp) (Figure 28)show the most common range of 9–11 s Tp during winter and 7–9 s during summer. The occurrence of 9–11 Tp waves in the reporting period summer was much less than what has been observed in the entire record. Overall, the distribution of Tp was similar to the record.

Table 15 Brisbane – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	17/03/1993 10:30	7.4	4/03/2006 21:00	16.8
2	4/03/2006 9:00	7.2	5/03/2004 17:30	14.3
3	28/01/2013 7:30	7.1	17/03/1993 3:30	13.1
4	5/03/2004 17:30	7.0	2/05/1996 14:00	12.8
5	2/05/1996 20:30	6.9	15/02/1995 6:30	12.2

6	15/02/1995 6:00	6.4	28/01/2013 7:30	12.1
7	23/08/2008 23:00	6.4	15/02/1996 19:00	12.1
8	12/06/2012 9:30	6.4	24/08/2008 2:00	11.5
9	6/06/2012 19:30	6.3	26/03/1998 7:00	11.5
10	31/12/2007 3:00	6.3	6/06/2012 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
28/08/2014 10:00	4.6 (4.8)	7.4 (8.9)	10.9	From the 26th to the 28th, there was a low pressure system off southeast Queensland and several coastal troughs with embedded low pressure systems.
05/02/2014 23:00	4.4 (4.8)	7.6 (9.0)	9.4	Low [1000 hPa] situated off the Central NSW coast with a trough extending northward along the coast.

Denotes peak Hsig event

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

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

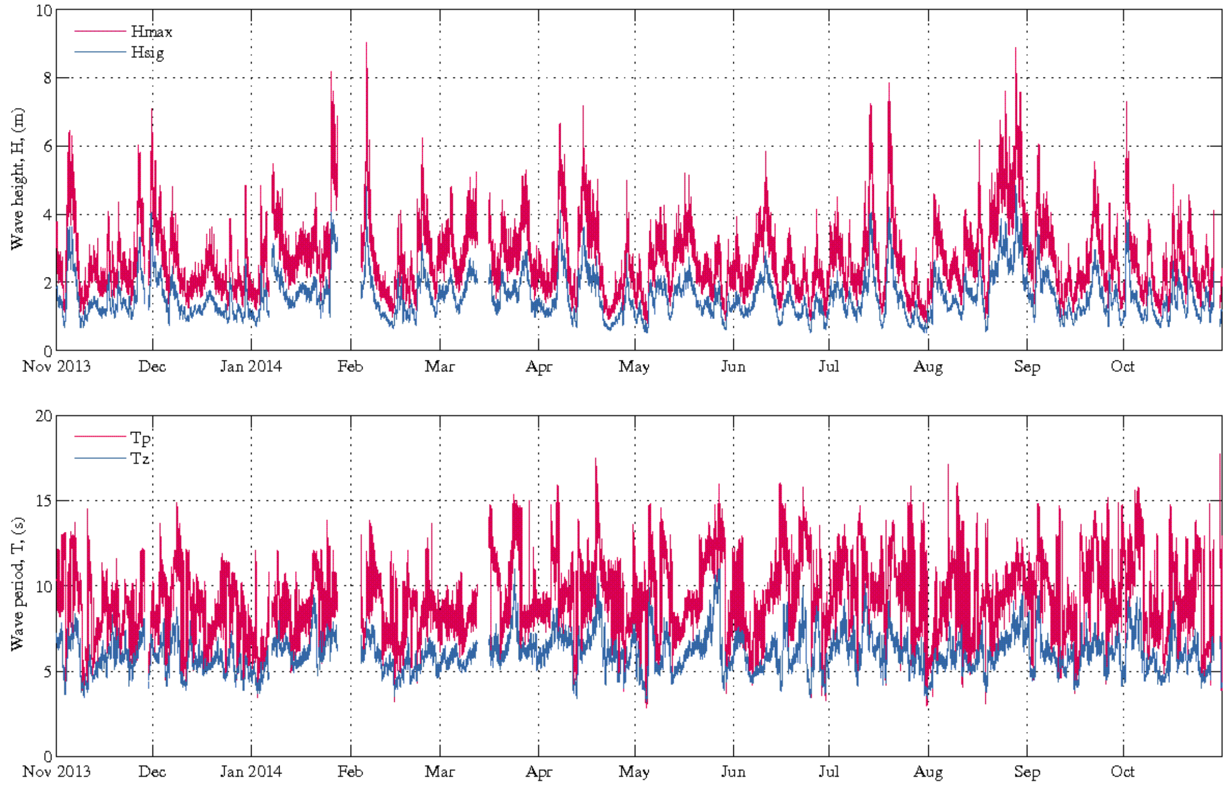


Figure 23 Brisbane – Daily wave recordings

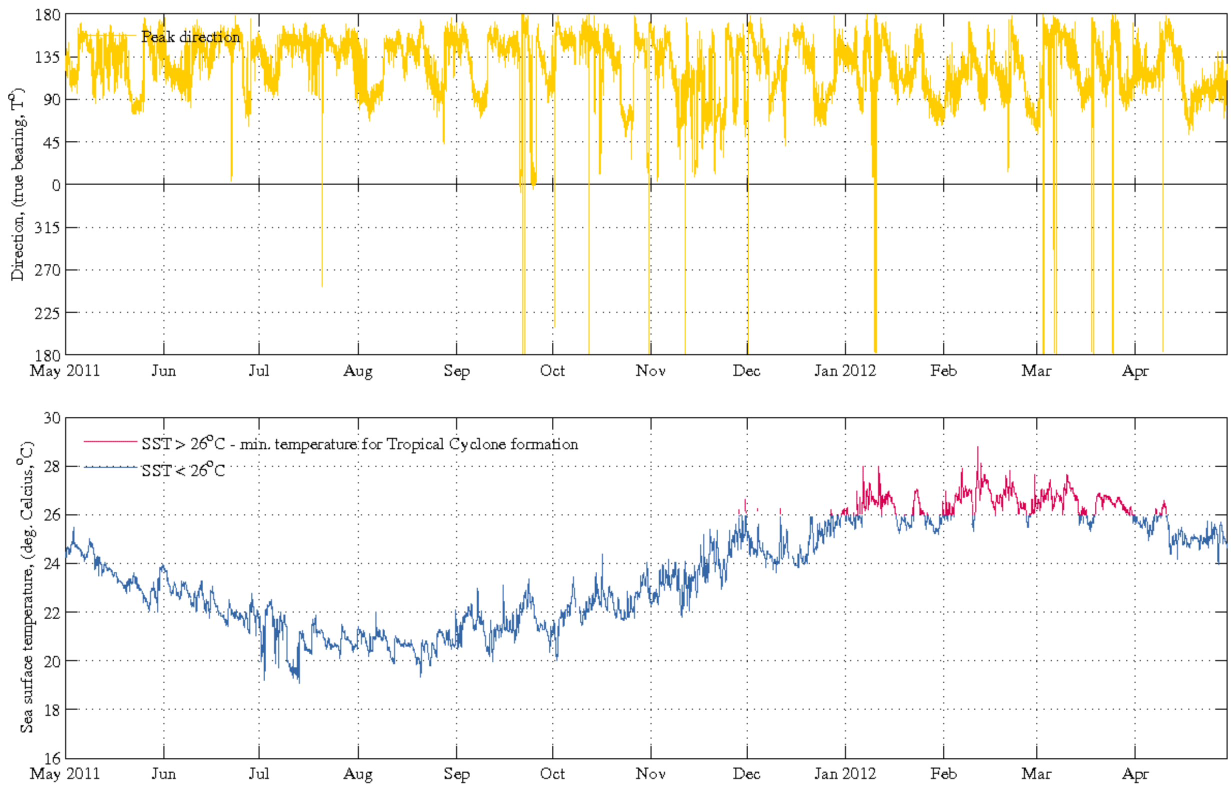


Figure 24 Brisbane – Sea surface temperature and peak wave directions

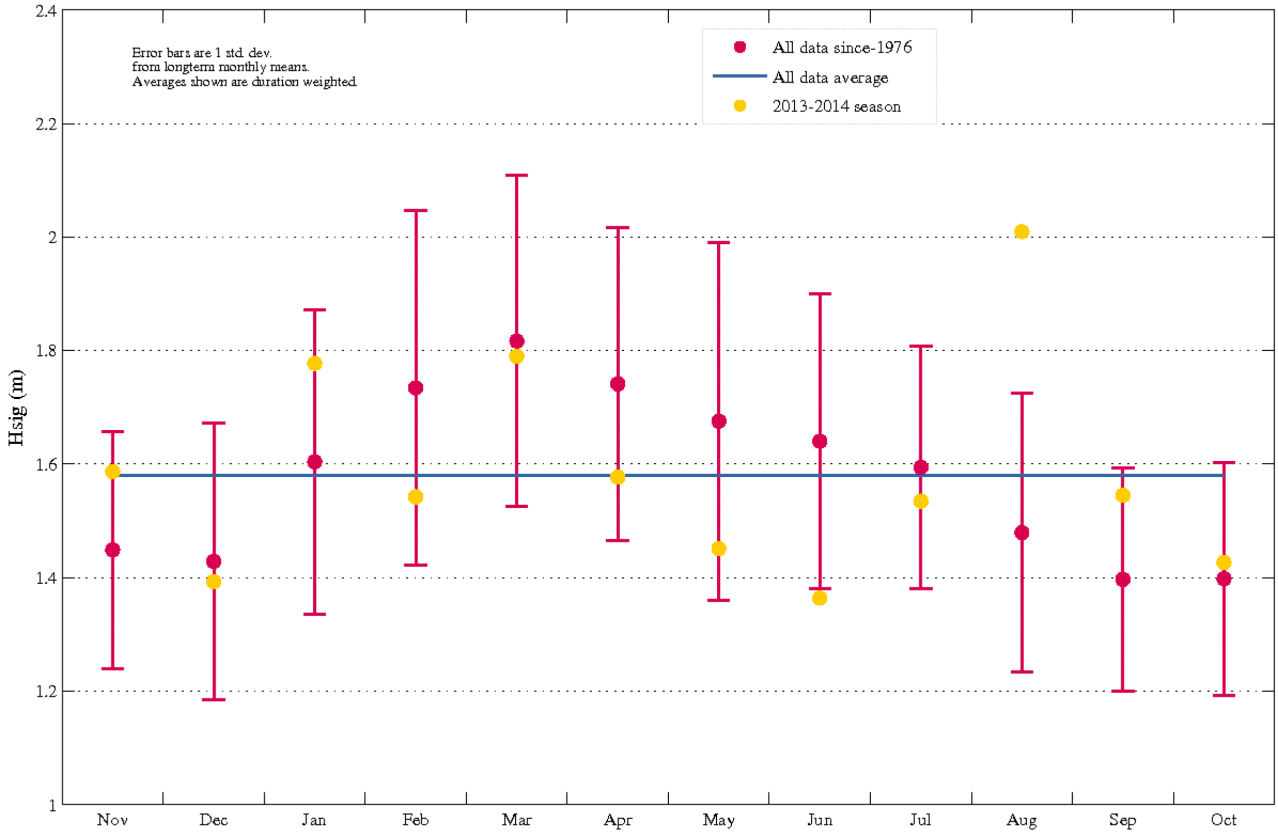


Figure 25 Brisbane – Monthly average wave height (Hsig) for seasonal year and for all data

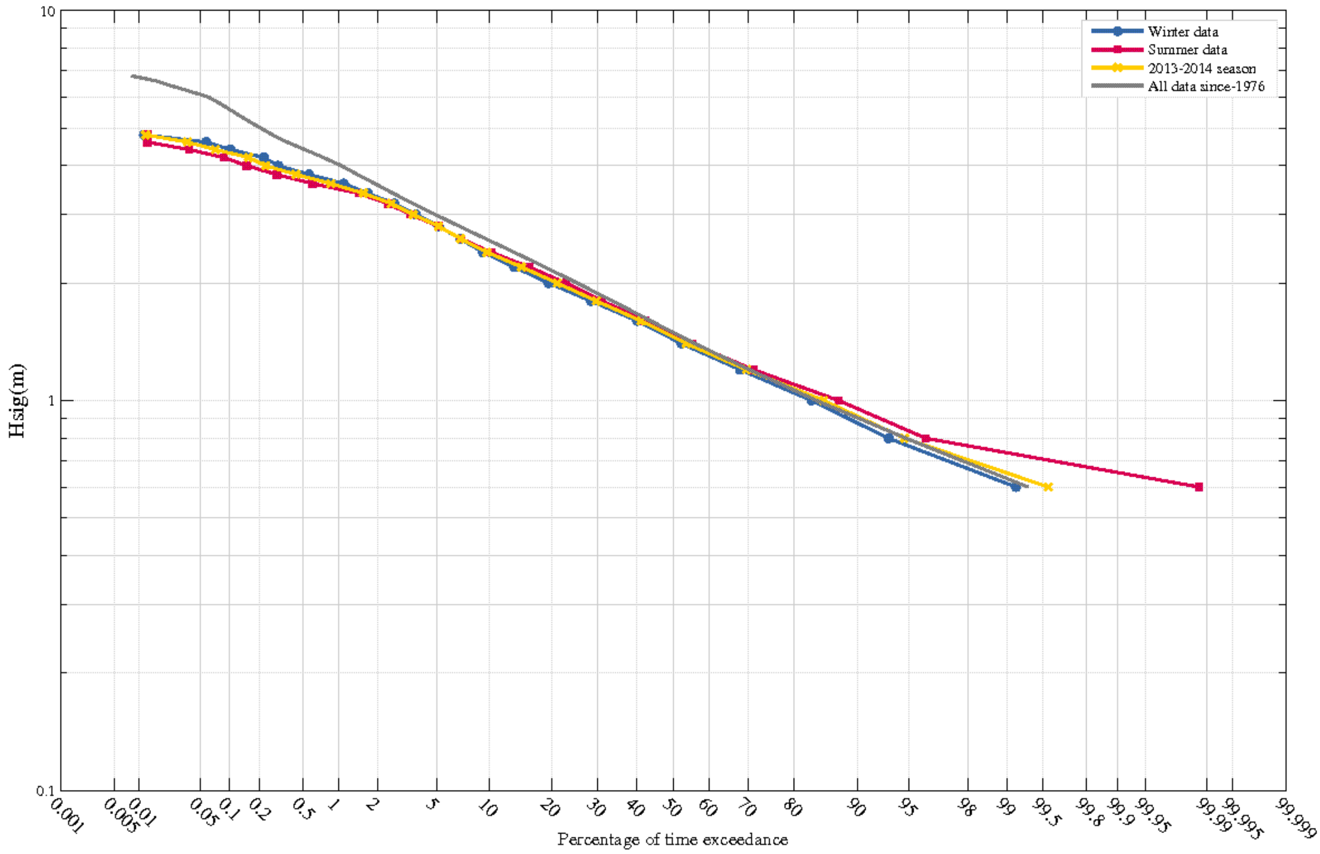


Figure 26 Brisbane – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

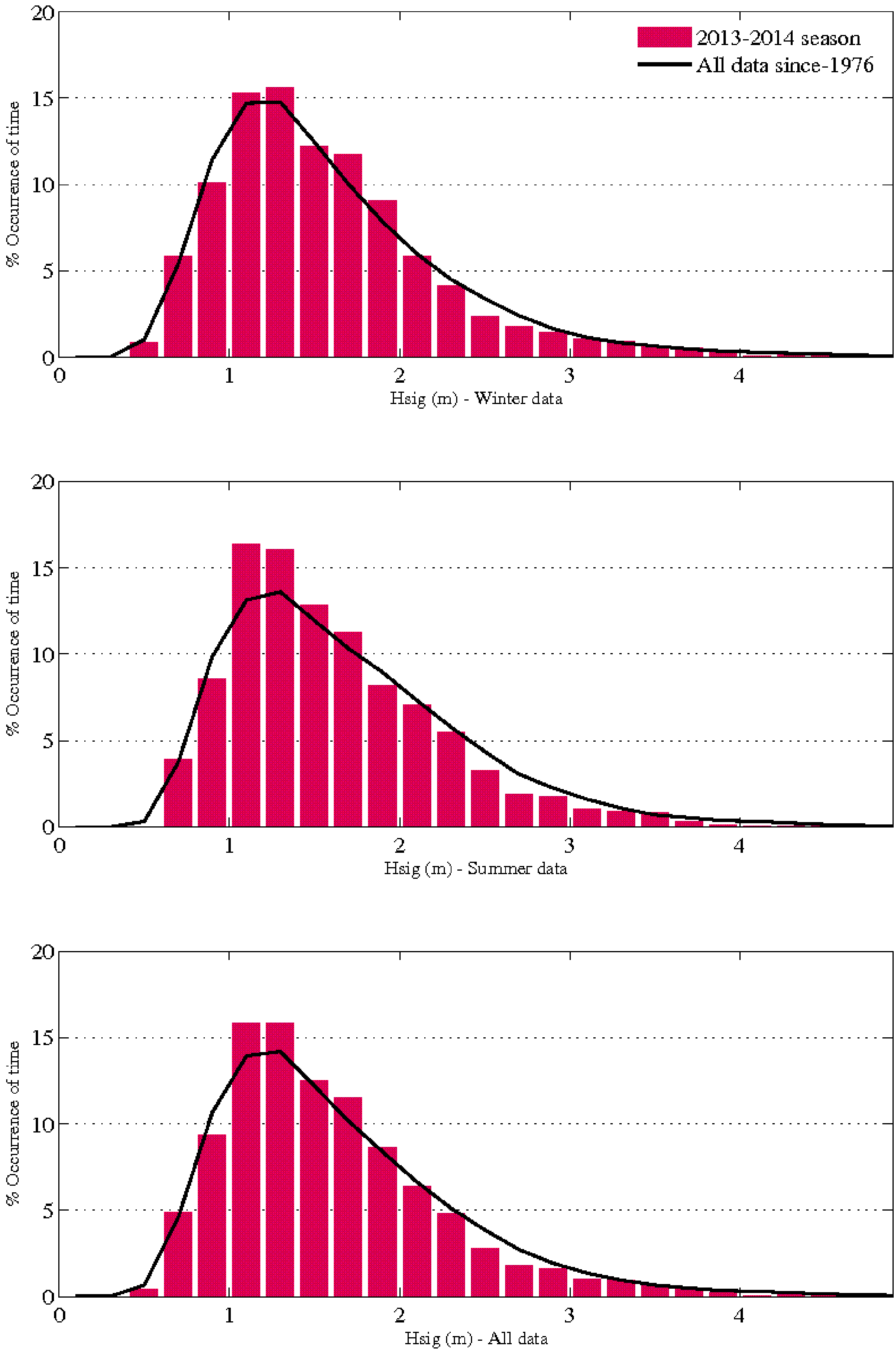


Figure 27 Brisbane – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

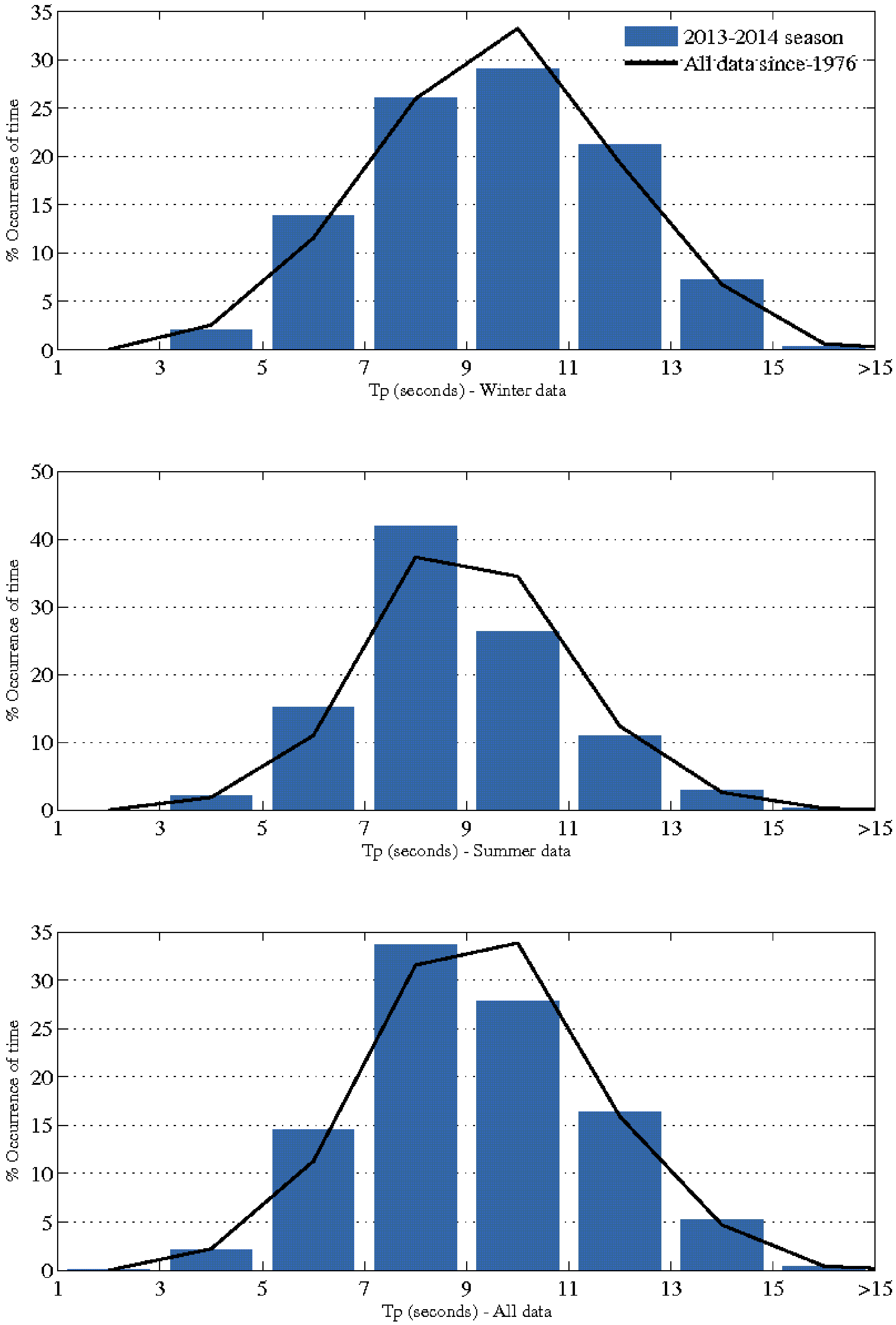


Figure 28 Brisbane – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

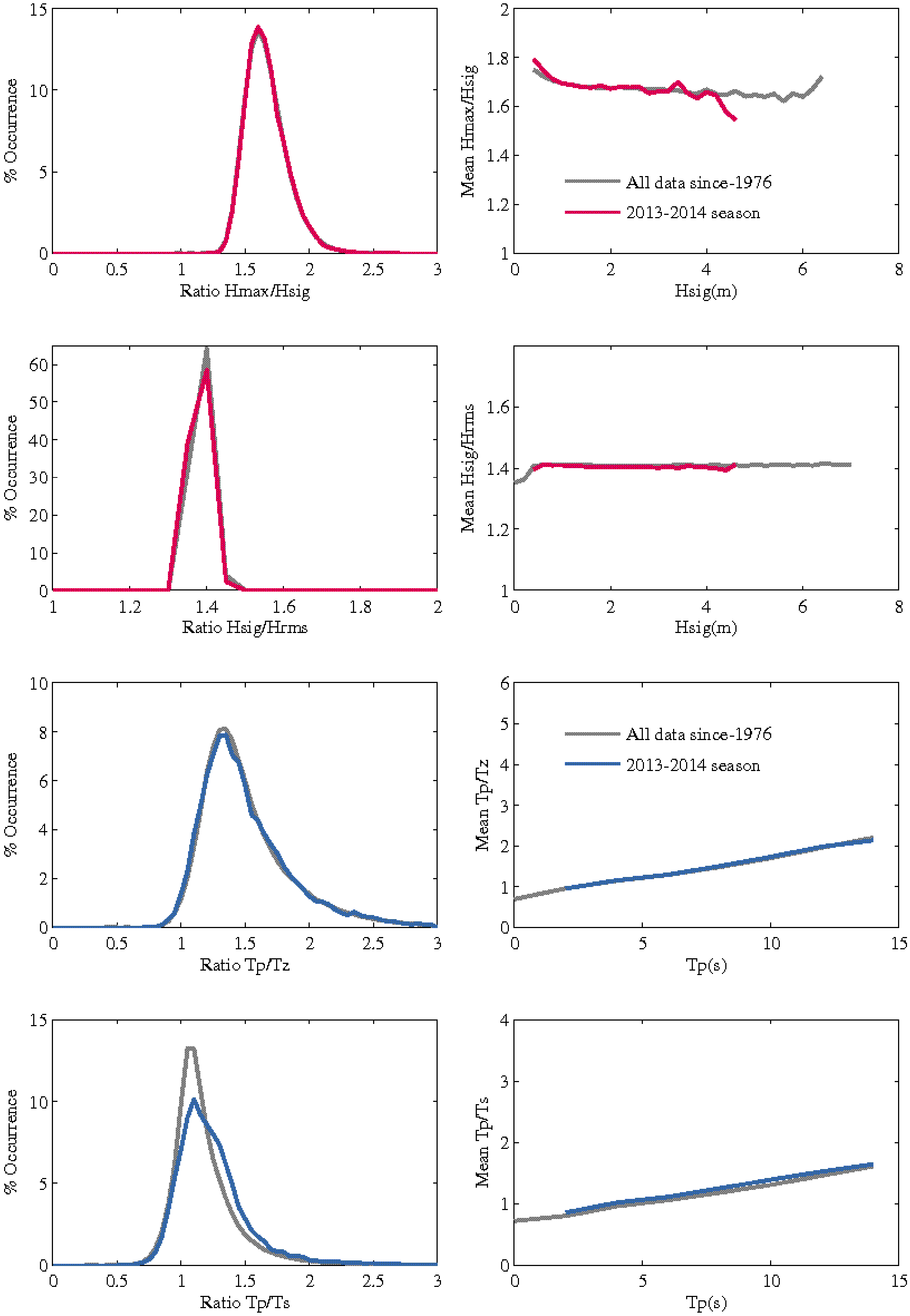
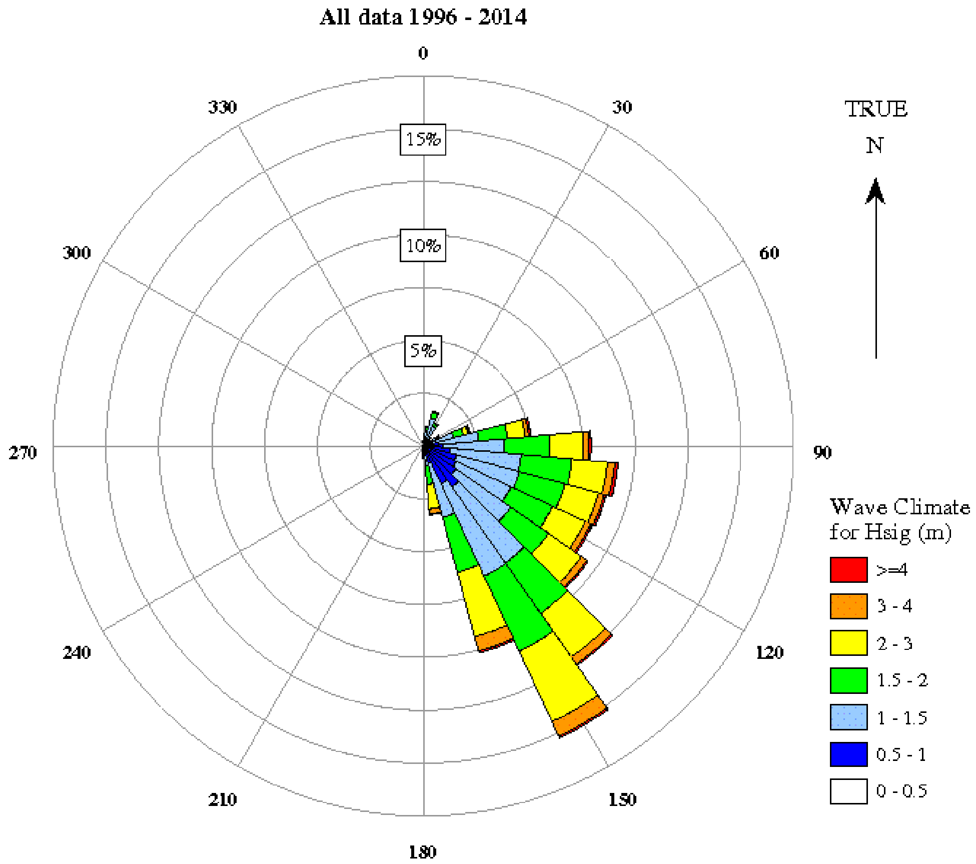


Figure 29 Brisbane – Wave parameter relationships



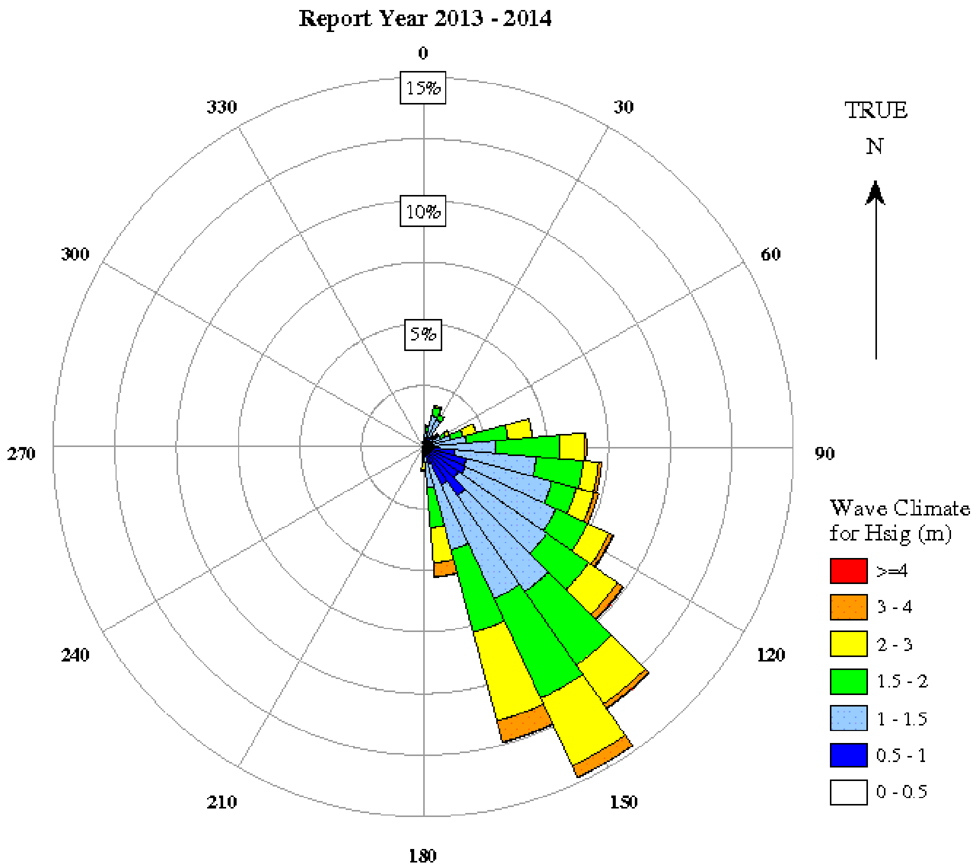


Figure 30 Brisbane – Directional wave rose

7.4 North Moreton

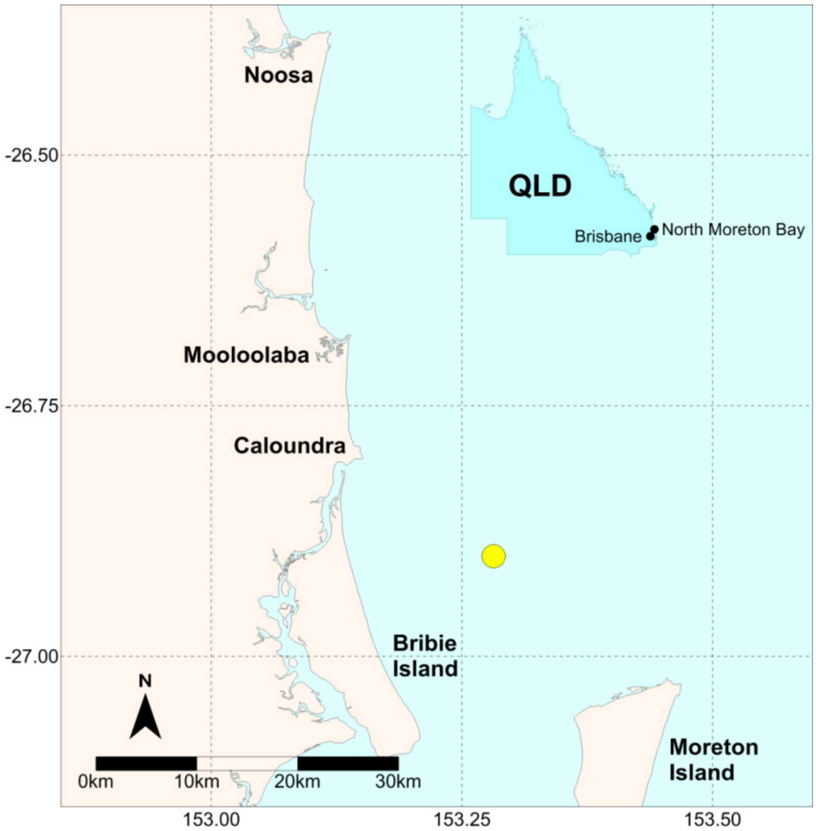


Figure 31 North Moreton – Locality plan

Table 17 North Moreton – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	31/10/2010	0.05 years	73262	4.7
2013 -14	1/11/2013	0.96 days	17473	1

Table 18 North Moreton – Buoy deployments during the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°54.930'S	153°16.842'E	35	26/04/2013	14/06/2014
26°54.910'S	153°16.730'E	35	14/06/2014	current

7.4.1 North Moreton – seasonal overview

The North Moreton wave buoy has been operational for just over four years with an overall data return of 98.9 percent. The data record for the period November 2013 to October 2014 was exceptional, with total gaps of only 1 day, equivalent to 99.7 percent data return. The buoy was replaced once during the reporting period on 14 June 2014 (Table 18).

An east coast low pressure system in March resulted in the highest waves for the reporting period with a significant wave height (Hsig) and maximum wave height (Hmax) of 2.8 m and 4.8 metres. This was the 10th highest ranking Hsig and 6th highest ranking Hmax recorded at North Moreton (Table 19). The relatively short record (four years) means that the highest top ten ranked waves is expected to be exceeded frequently.

Time series of peak wave direction (Figure 33) show a dominant easterly direction with an occasional swing to the north. The location of the wave buoy with regards to Moreton Island restricts the recording of waves generated from the south east. The directional wave rose (Figure 39) also shows dominant incident waves from the east which is similar to the wave directions for the entire record.

The monthly average Hsig (Figure 32) varied from monthly long–term means throughout the reporting period. Many months experienced an average Hsig towards the bounds of one standard deviation (sd) where this exceeded -1 sd in December, April and July and exceeded +1 sd during August. The influence of two significant low pressure systems on the east coast (Table 20) in August is likely to have caused this exceedance. North Moreton has only been operational for four years so variability in monthly means is to be expected.

Percentage exceedance of Hsig (Figure 35) shows slightly higher waves occurring throughout summer than winter. The wave climate for the reporting period was similar to the entire record except heights of waves occurring less than 2 percent were greater for the entire record than the recent period. Histograms for occurrence of Hsig (Figure 36) show similarity to the entire record as well as varying wave climate distributions between summer and winter. The Hsig distribution of winter waves is skewed to the right with the highest occurring waves less than 1 metres. Summer has a more symmetrical distribution and hence a broader range of waves from 0.5–1.5 m Hsig. Histograms for occurrence of peak wave period (Tp) (Figure 37) generally show similar distributions between the reporting period and the entire record. Less occurrence of 9–11 seconds Tp waves throughout the reporting period are the most notable differences in comparison to the entire record. The most frequently occurring range was 6–7 seconds Tp.

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	25/12/2011 7:00	3.9	25/12/2011 7:00	7.3
3	19/02/2013 11:30	3.5	19/02/2013 15:30	6.3
4	28/06/2012 02:30	3.2	28/06/2012 05:30	5.7

5	17/01/2012 06:30	3	22/08/2011 8:30	5.7
6	12/10/2010 13:30	3	27/03/2014 22:30	5.7
7	12/06/2012 15:30	2.9	16/01/2011 22:00	5.7
8	11/08/2010 02:00	2.9	17/01/2012 6:30	5.6
9	08/12/2011 13:30	2.8	12/06/2012 13:00	5.5
10	27/03/2014 22:30	2.8	11/10/2010 14:00	5.4

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

Date	Hs (m)	Hmax (m)	Tp (s)	Event
27/03/2014 22:30	2.6 (2.8)	4.8 (5.7)	7.9	An east coast low pressure system with a central pressure of 1011 hPa
23/08/2014 18:30	2.4 (2.5)	3.9 (4.9)	9.4	An east coast low pressure trough with a central pressure of 1017 hPa
17/08/2014 05:00	2.3 (2.6)	4.1 (4.7)	8.1	An east coast low pressure system with a central pressure of 998 hPa

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.

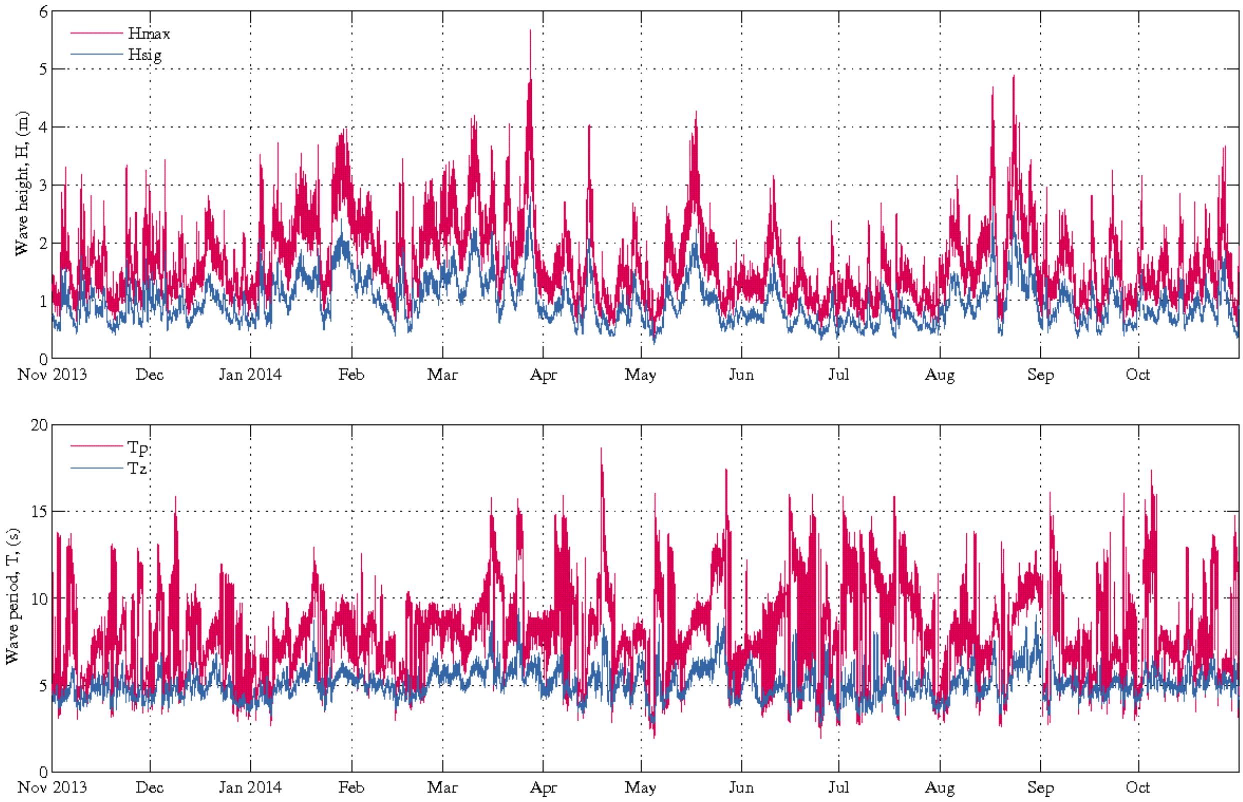


Figure 32 North Moreton – Daily wave recordings

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

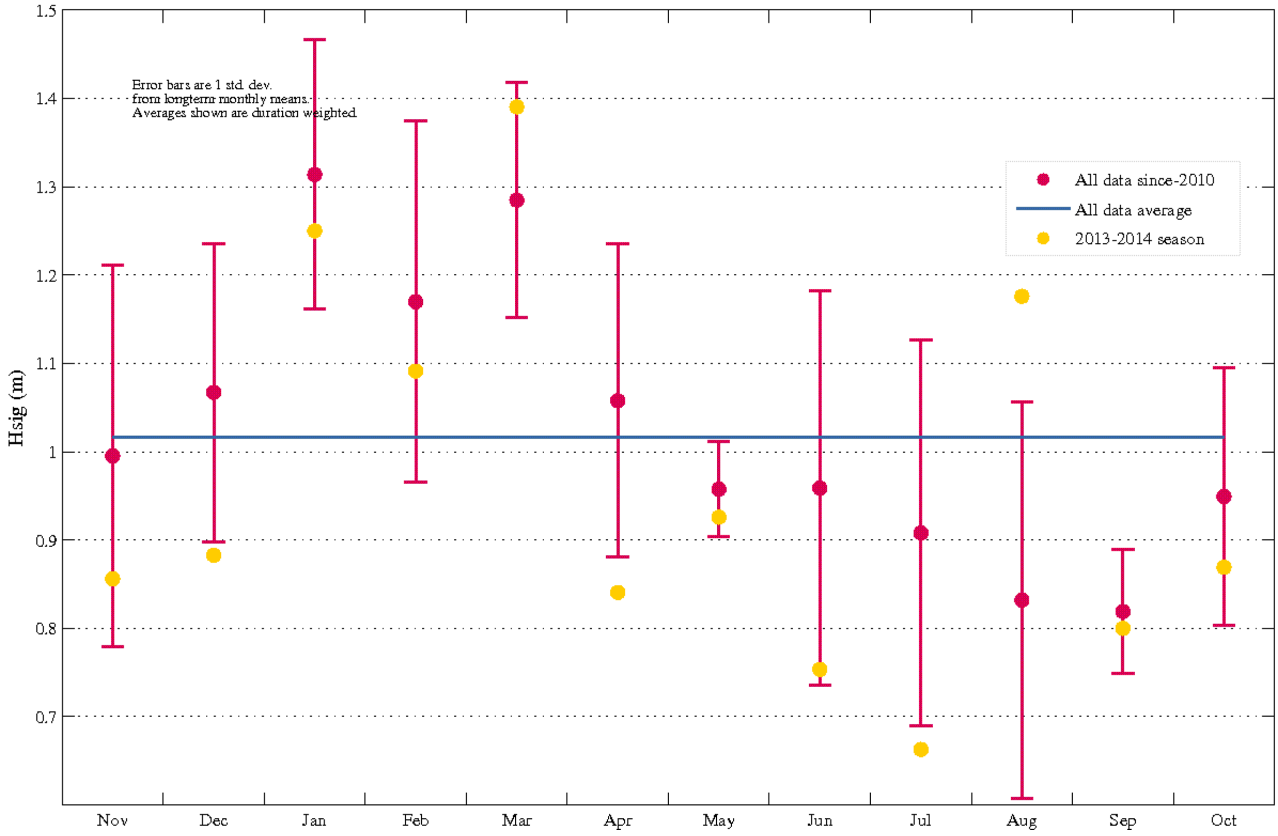


Figure 34 North Moreton – Monthly average wave height (Hsig) for seasonal year and for all data

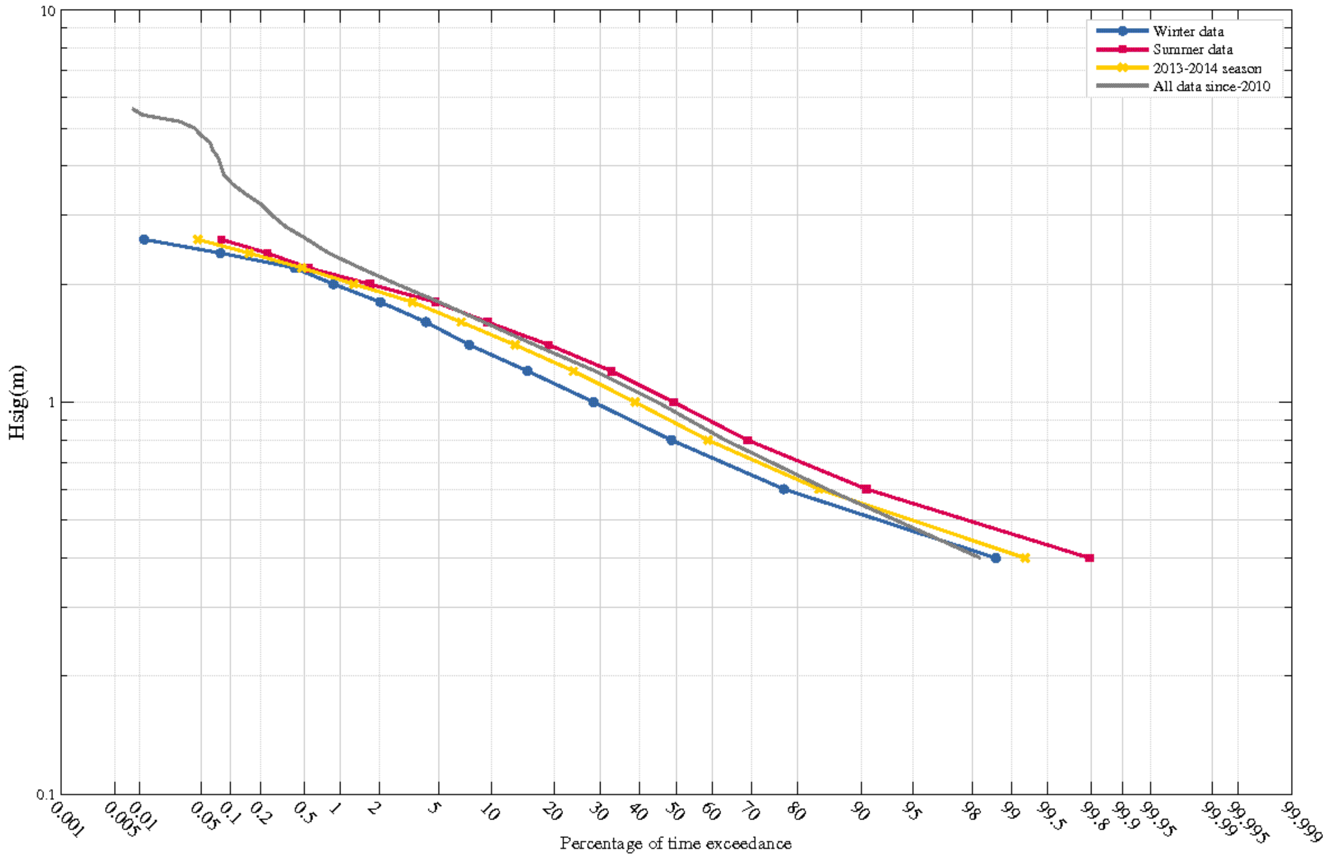


Figure 35 North Moreton – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

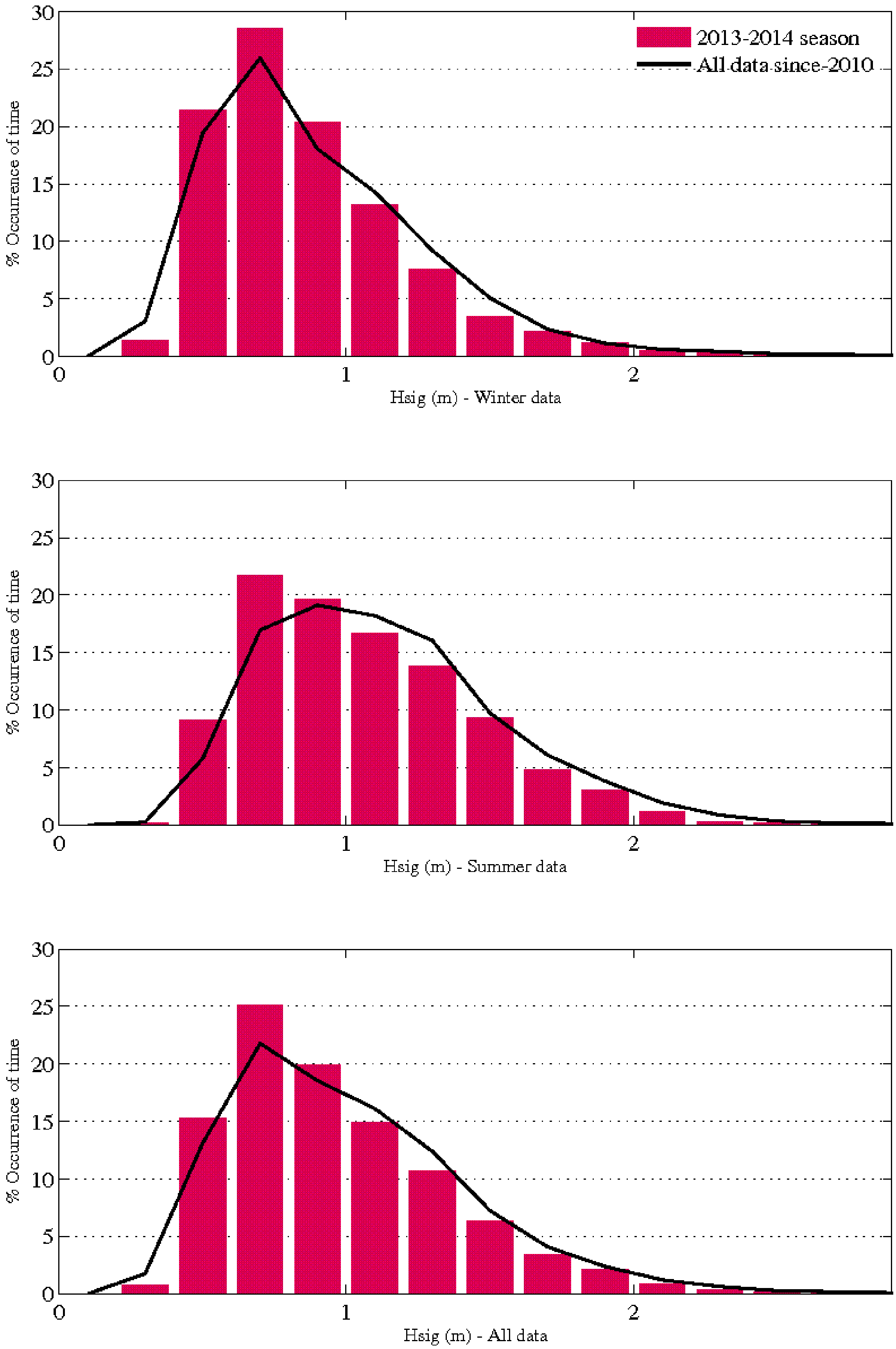


Figure 36 North Moreton – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

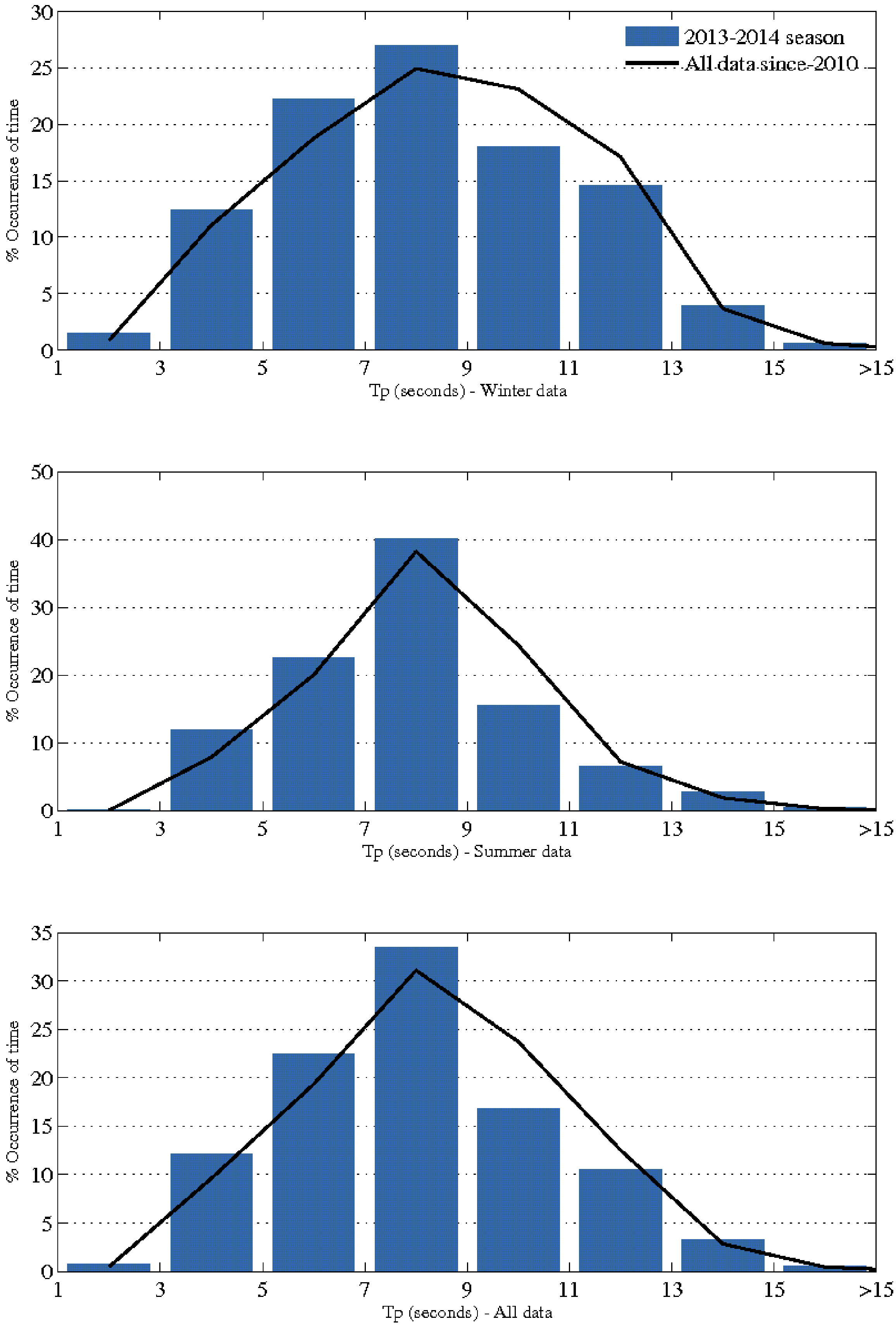


Figure 37 North Moreton – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

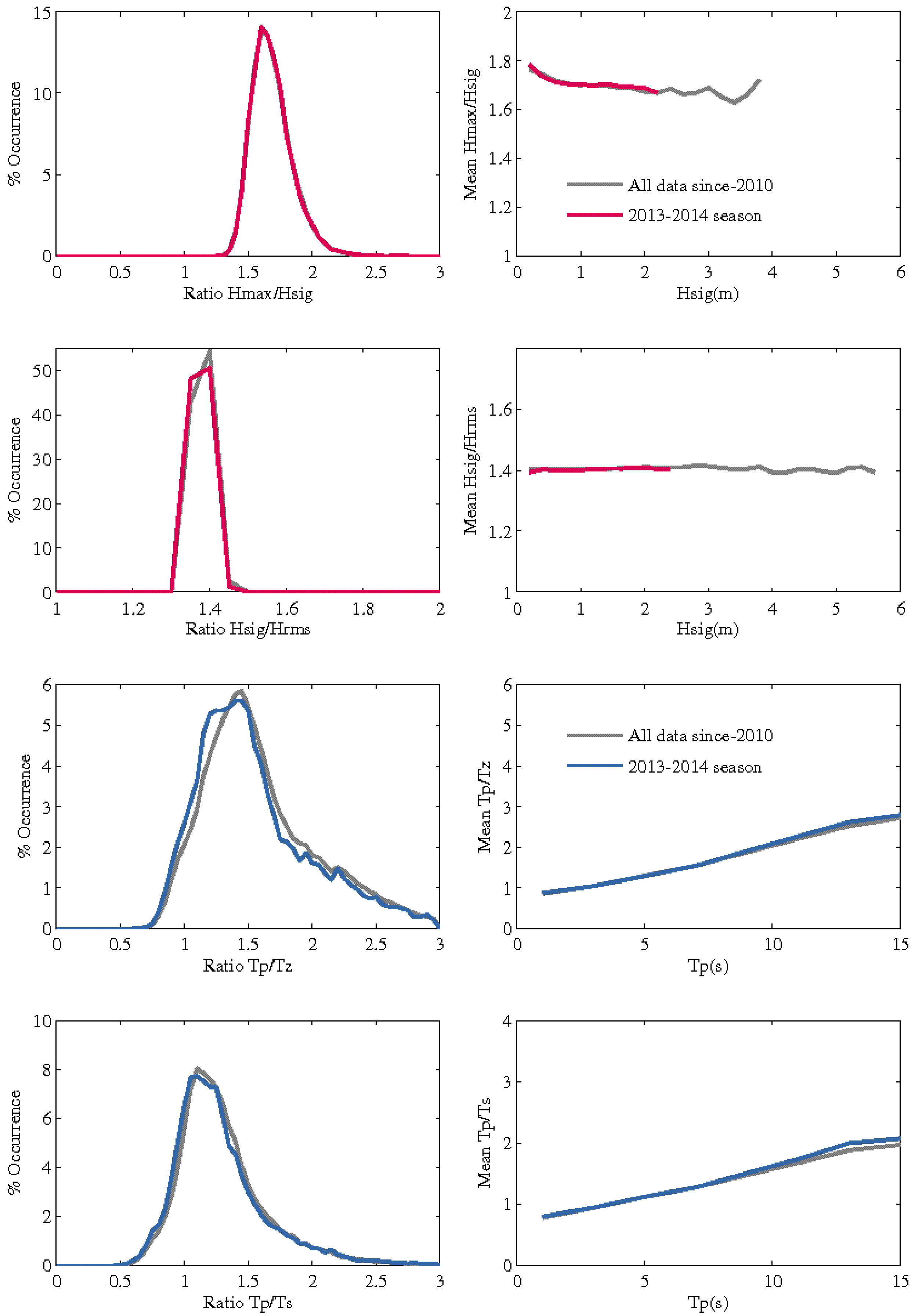


Figure 38 North Moreton – Wave parameter relationships

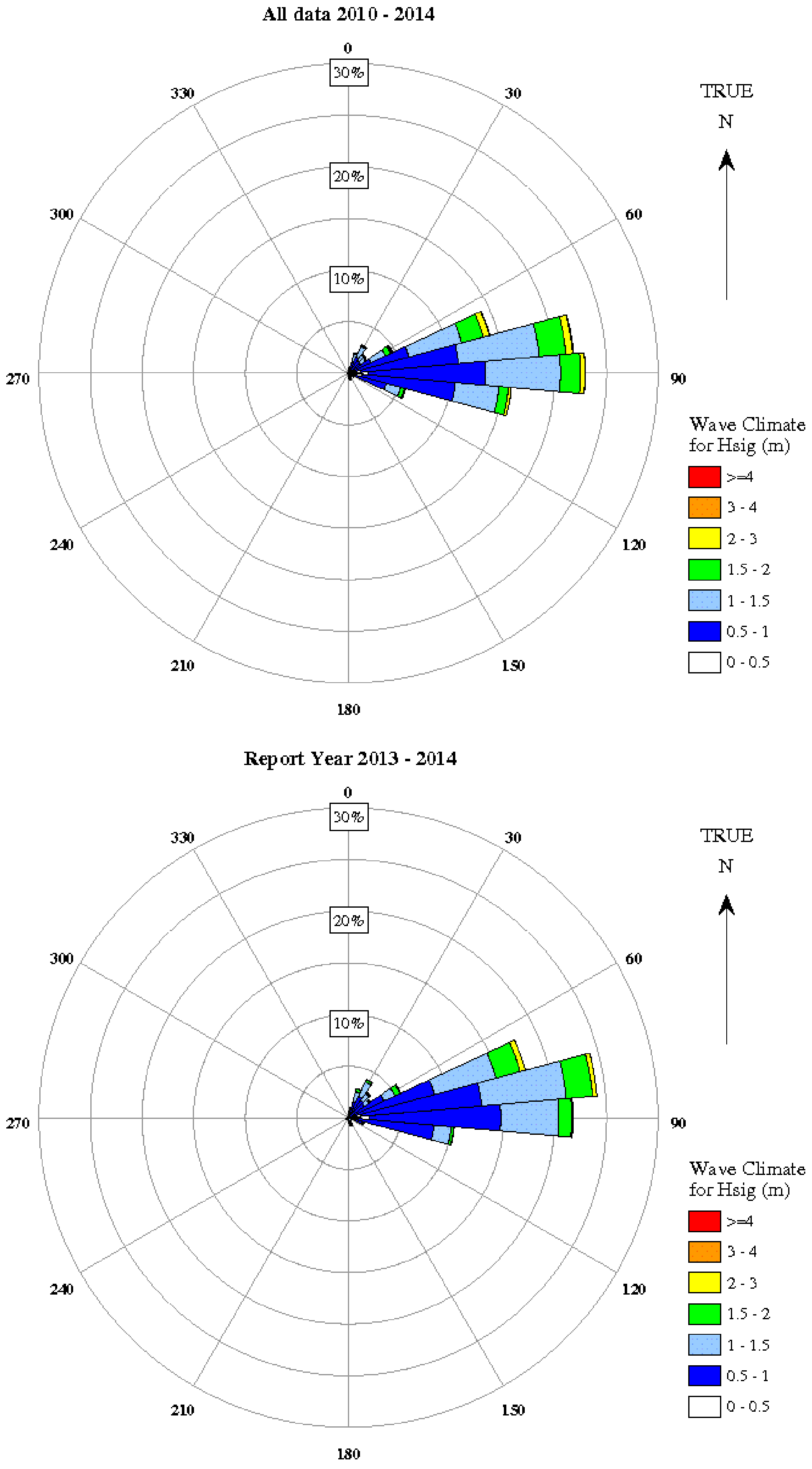


Figure 39 North Moreton – Directional wave rose

7.5 Caloundra

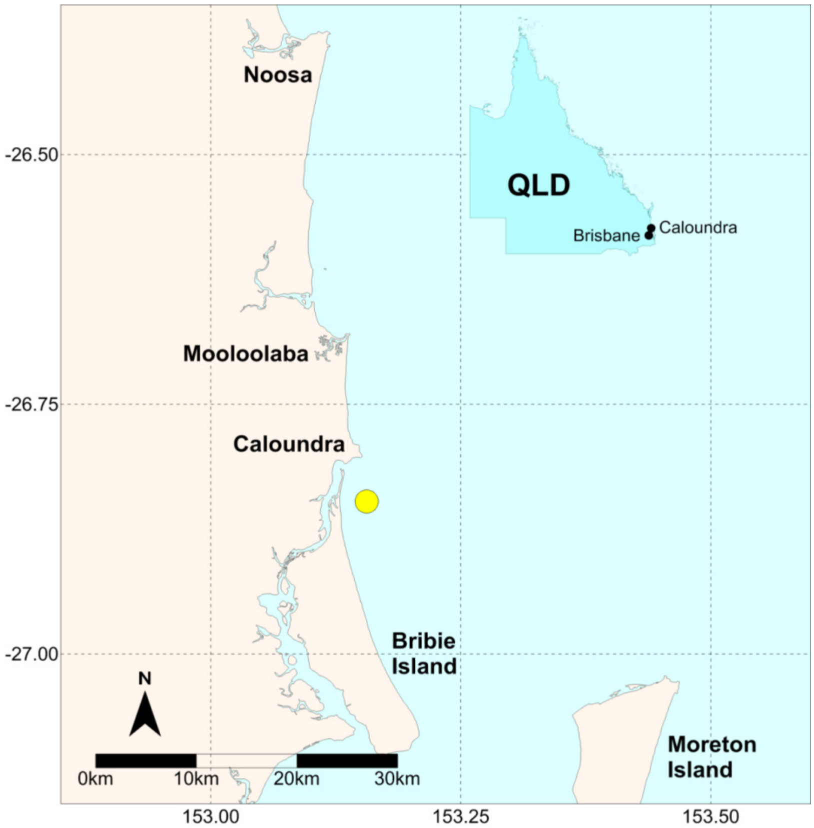


Figure 40 Caloundra – Locality plan

Table 21 Caloundra – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2013	15.04 days	16797	1.5
2013 -14	1/11/2013	15.04 days	16797	1

Table 22 Caloundra – Buoy deployments for 2012–13 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
26°50.855'S	153°09.340'E	12	26/10/2013	02/09/2014
26°50.999'S	153°09.000'E	14	02/09/2014	current

7.5.1 Caloundra – seasonal overview

The Caloundra wave buoy has only recently become operational. It was deployed on 26 April 2013 and has continued to record wave data since. There is a large break in the recorded wave data beginning 26 October 2013 as a result of a power issue on board the buoy. Due to the relatively short data set available, this report has made no comments or comparisons against any historical data. Additionally, since only six months of wave data has been recorded from the Caloundra site no comment or comparison can be made on the differences between the summer and winter wave climates.

Figure 45 shows the most common significant wave height (Hsig) 0.6m–0.8m and the most common peak period (Tp) being 9–11 seconds during this reporting period. The plot of wave direction (Figure 42) showed a dominant easterly direction with an occasional swing to the north east during August, September and October. The temperature (sea surface temperature, SST) measured in the buoy hull showed the recorded values ranging from 18° C to 24° C between April and October 2013.

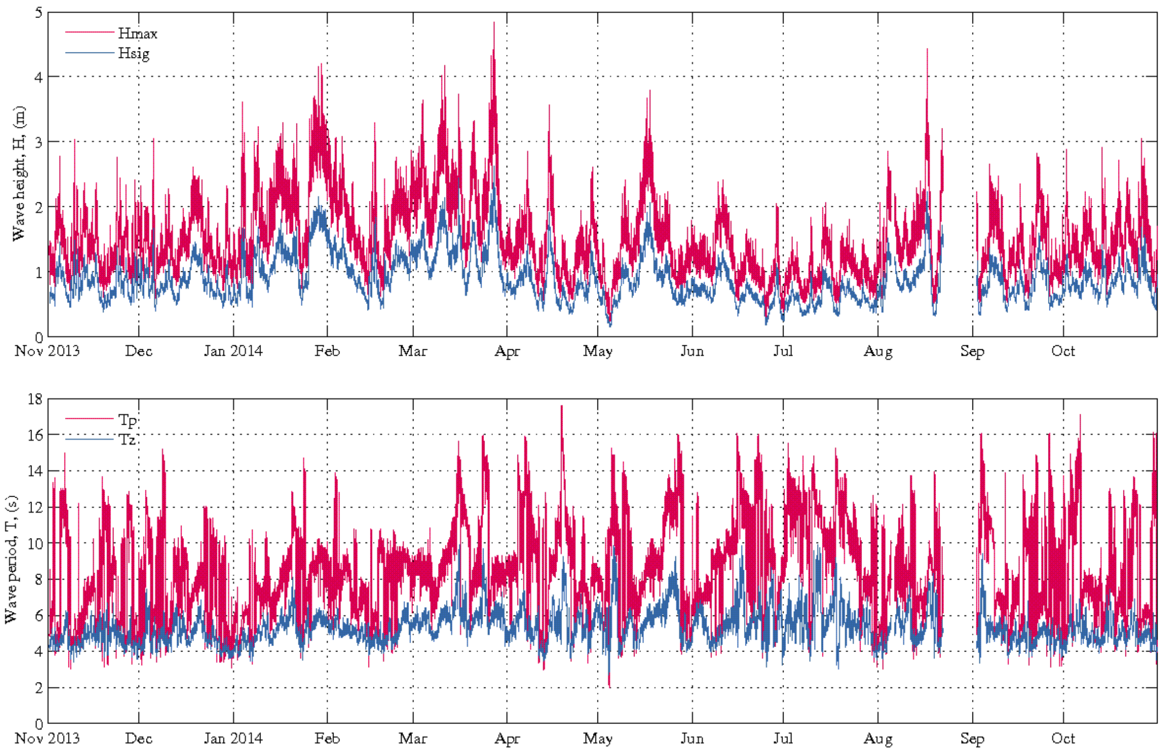


Figure 41 Caloundra – Daily wave recordings

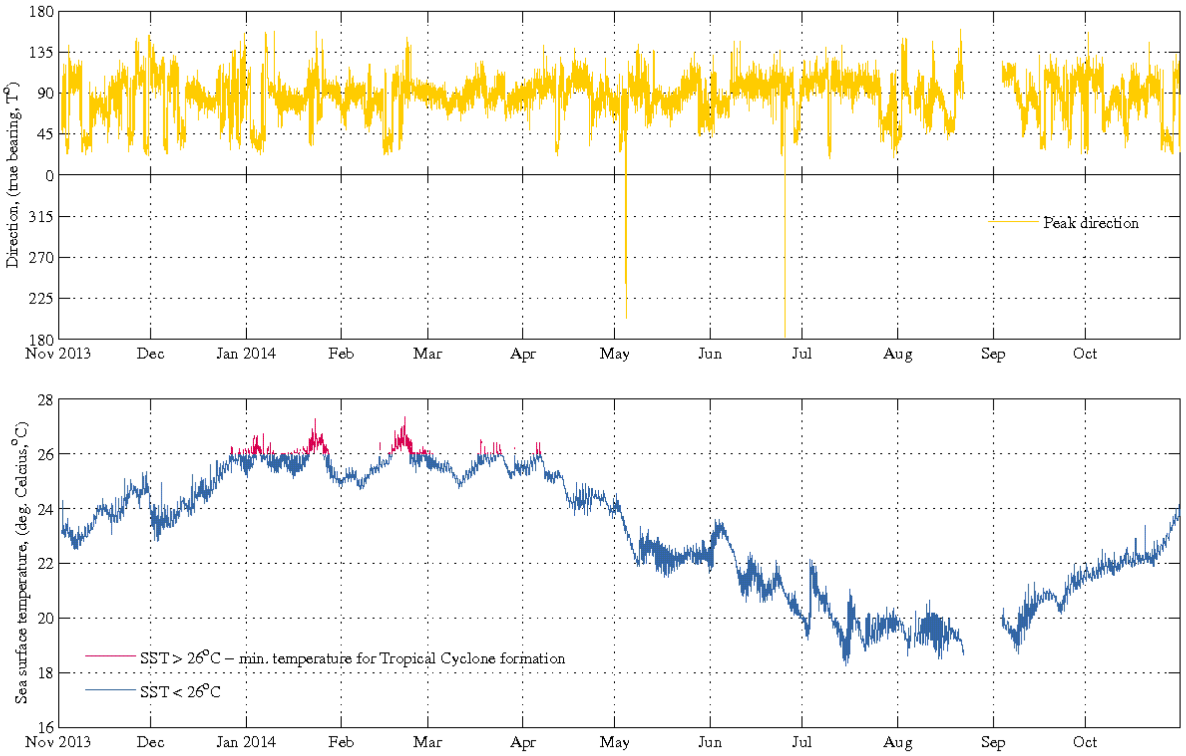


Figure 42 Caloundra – Sea surface temperature and peak wave directions

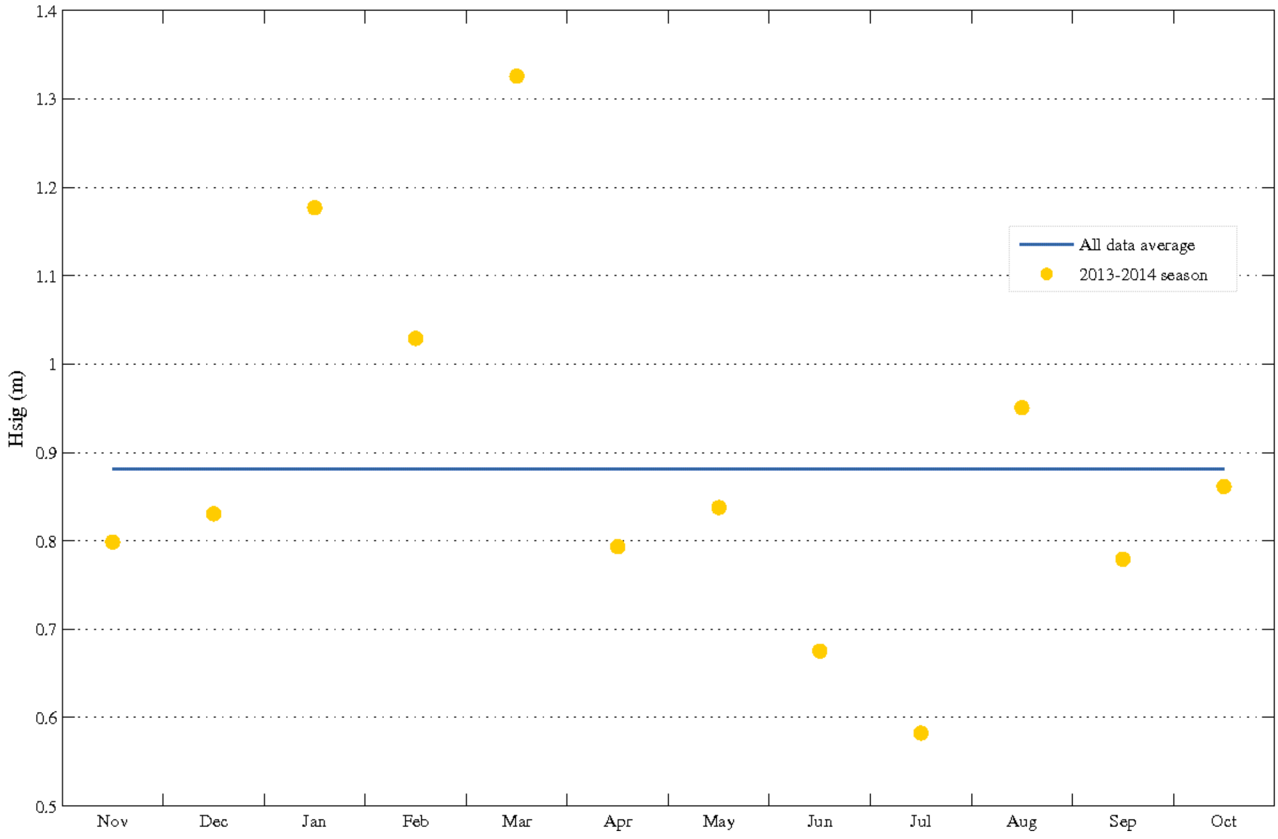


Figure 43 Caloundra – Monthly average wave height (Hsig) for seasonal year and for all data

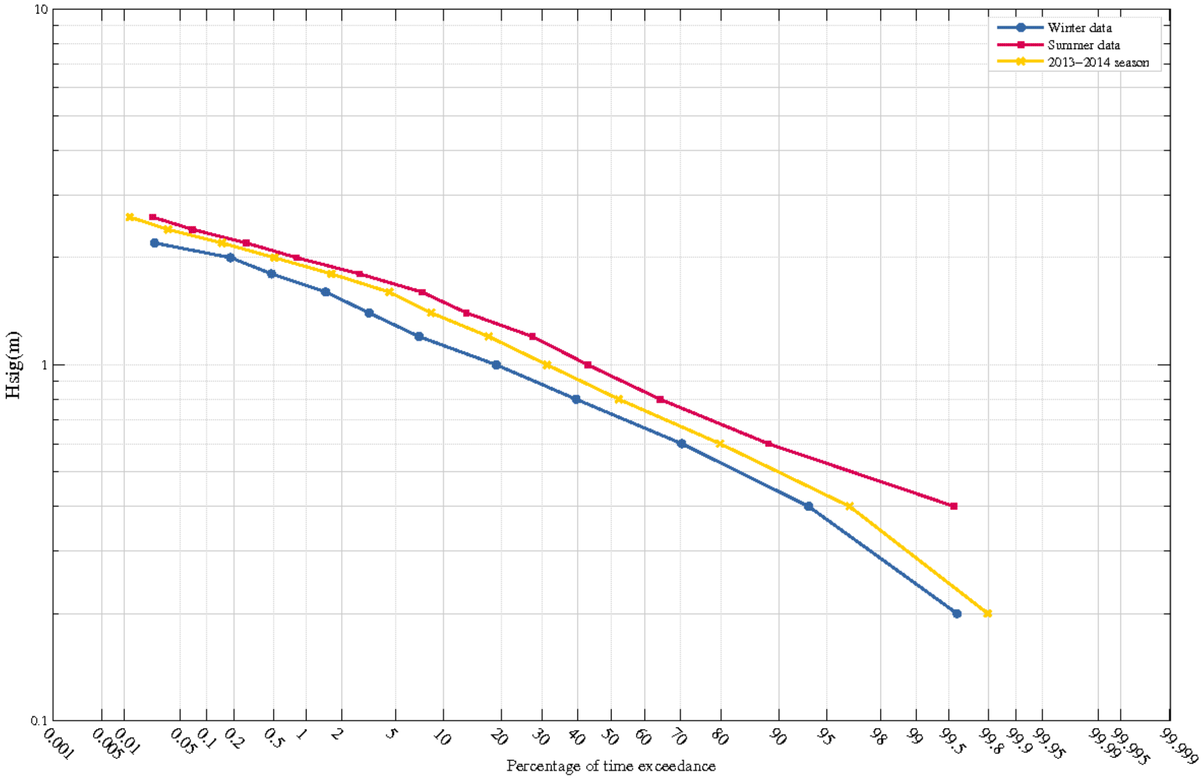


Figure 44 Caloundra – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

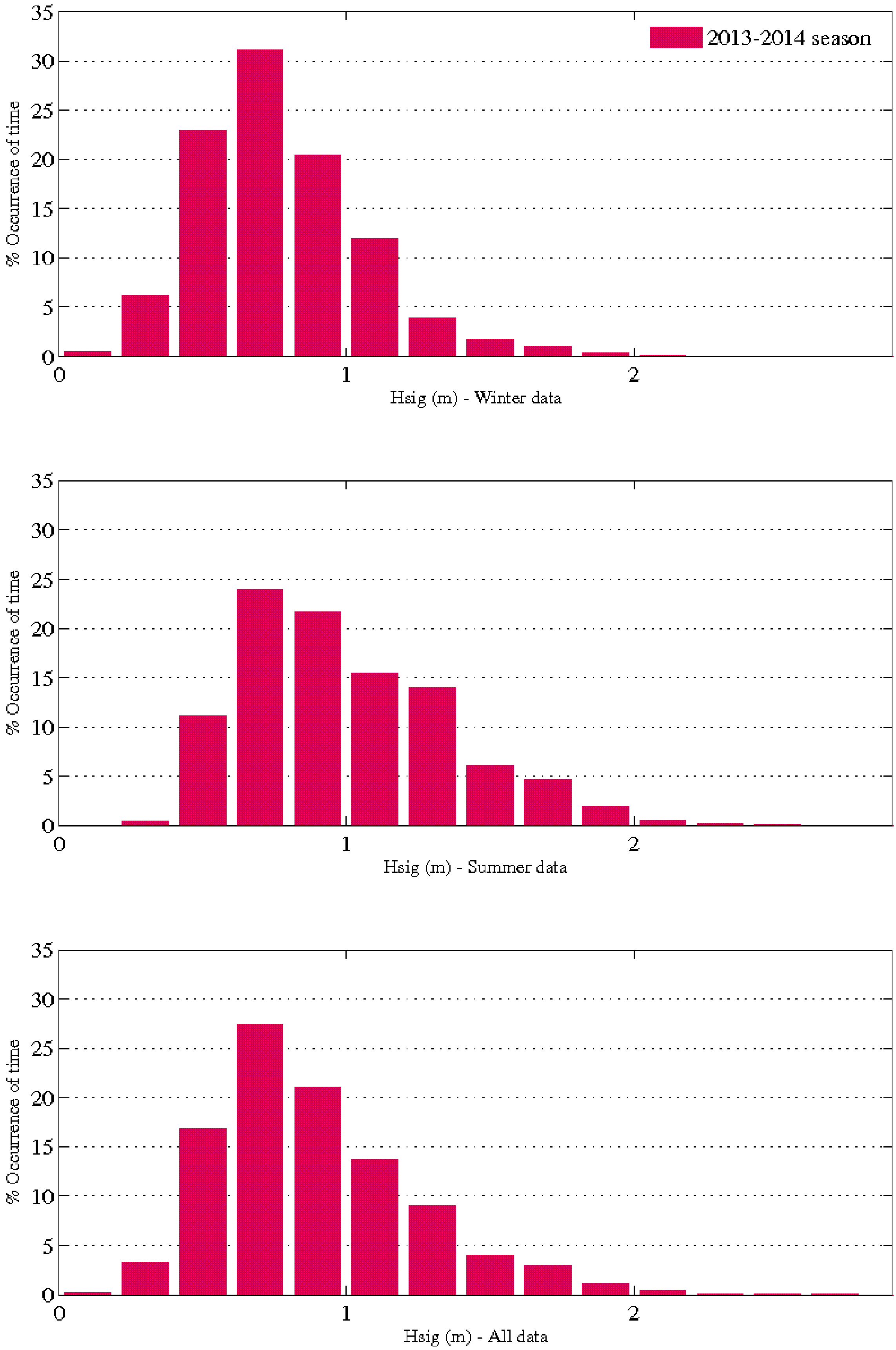


Figure 45 Caloundra – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

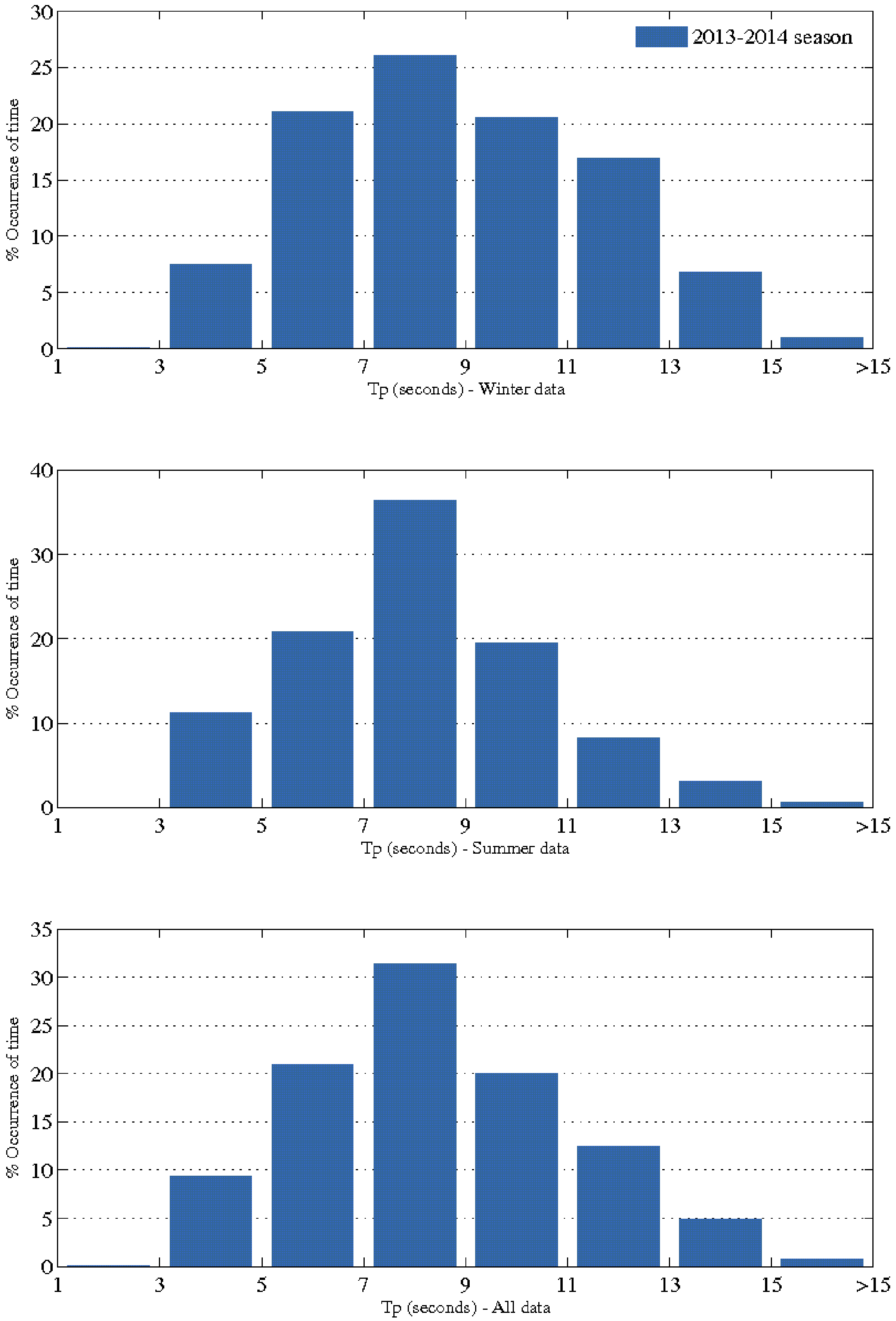


Figure 46 Caloundra – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

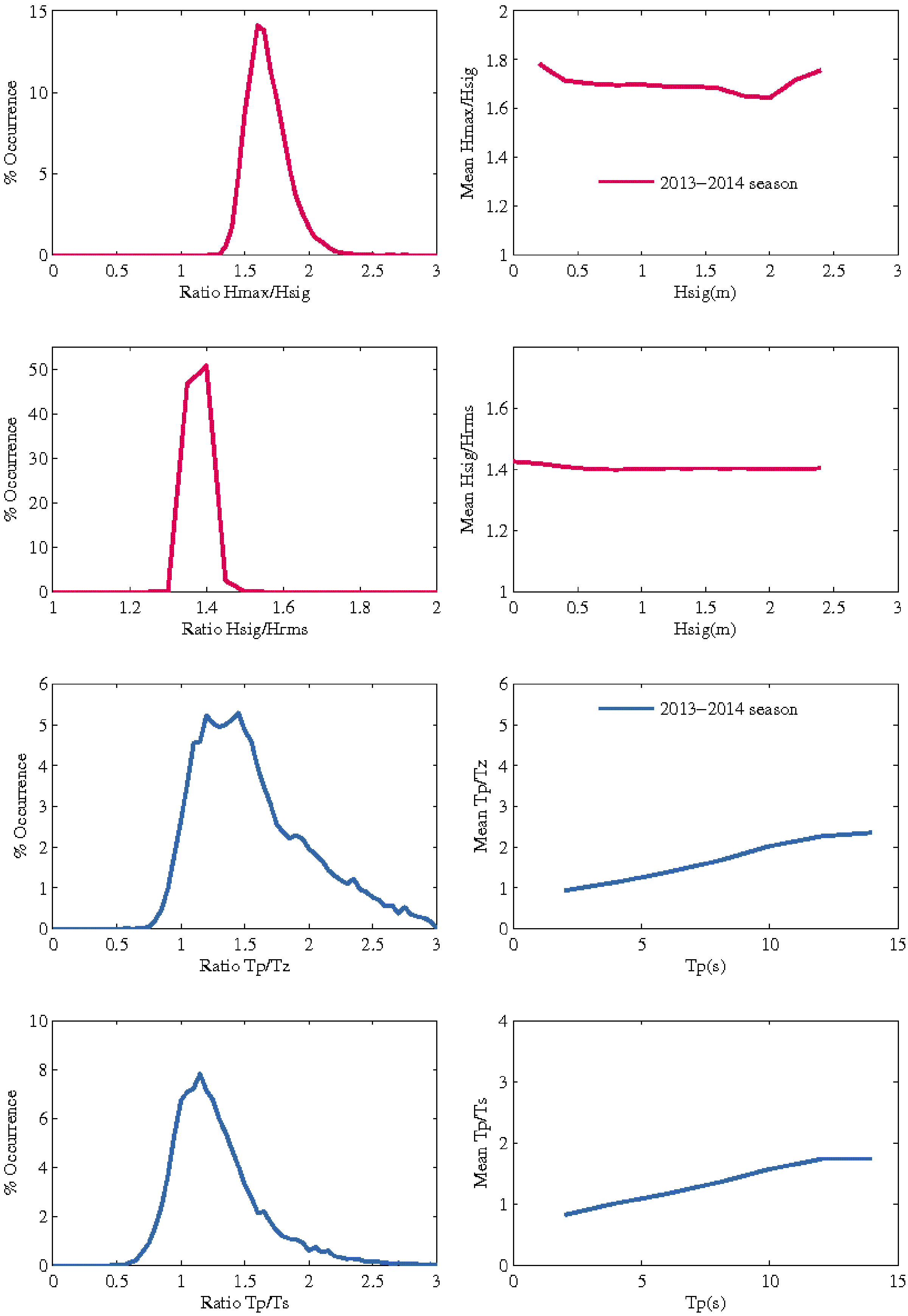


Figure 47 Caloundra - Wave parameter relationships

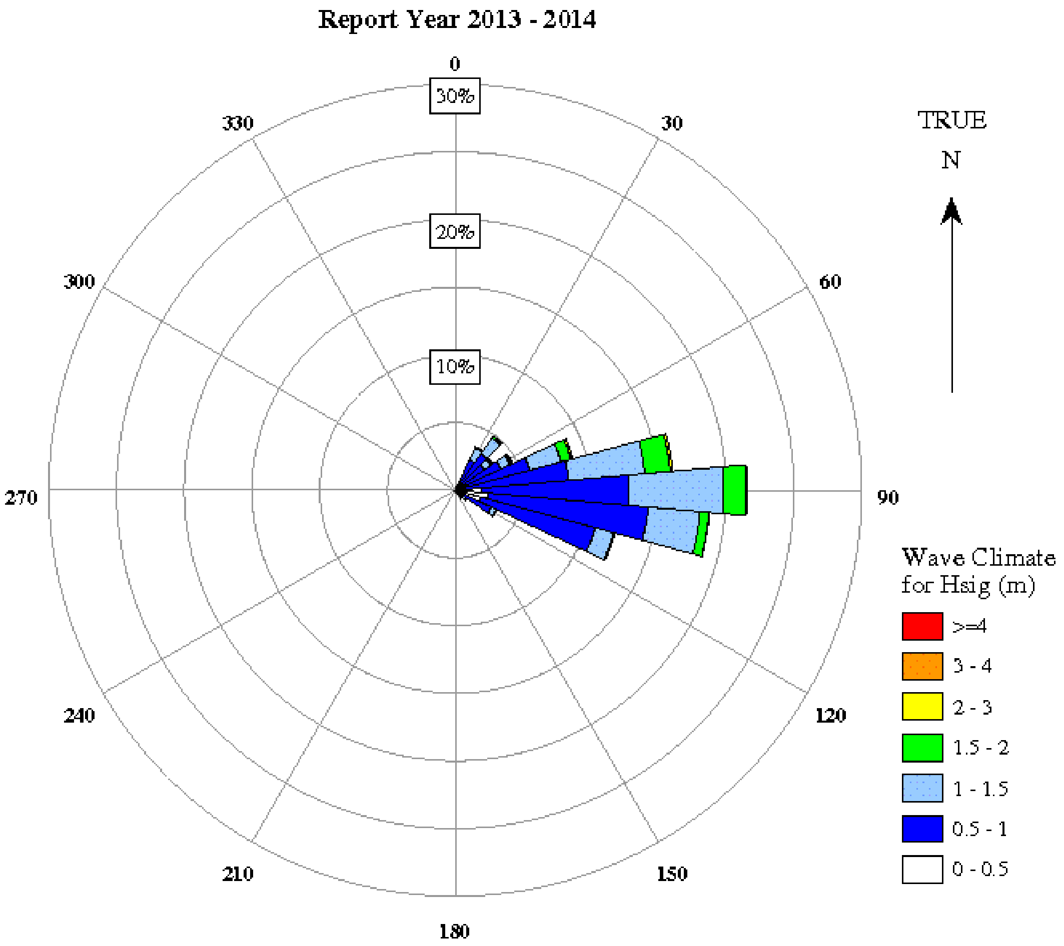


Figure 48 Caloundra – Wave rose

7.6 Mooloolaba

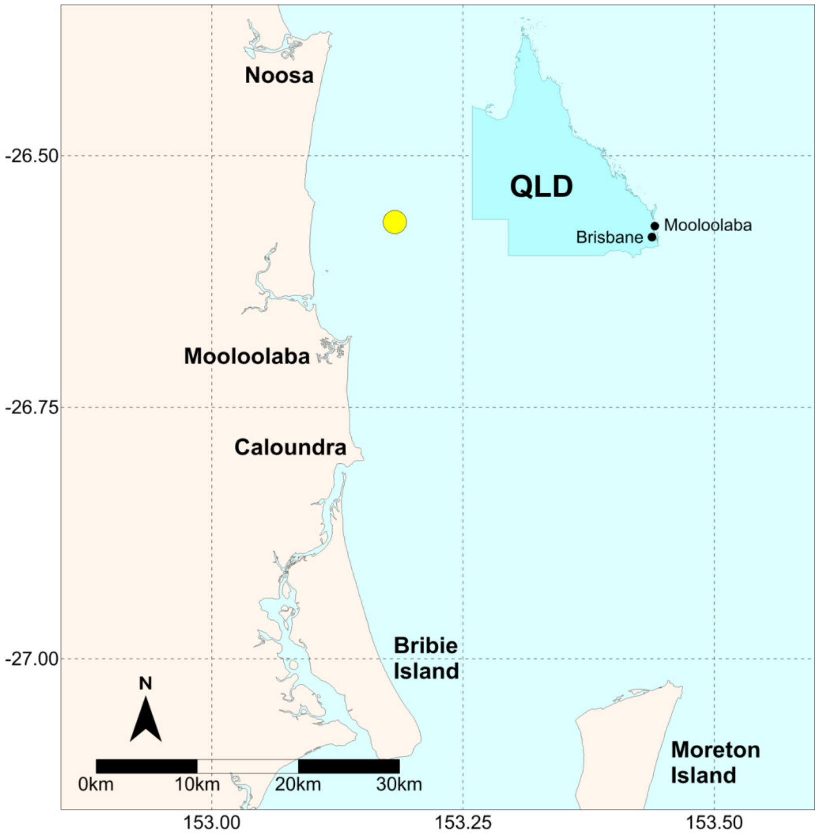


Figure 49 Mooloolaba – Locality plan

Table 23 Mooloolaba – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	01/05/2000	0.79 years	235046	14.5
2013 -14	1/11/2013	15.75 days	16797	1

Table 24 Mooloolaba – Buoy deployments for 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date	Reason for change
26°33.960'S	153°10.920'E	32	16/12/2012	30/03/2014	Normal change
26°34.009'S	153°10.872'E	33	30/03/2014	16/07/2014	Lost comms.
26°33.960'S	153°10.870'E	32	16/07/2014	current	-

7.6.1 Mooloolaba – seasonal overview

The Mooloolaba wave buoy has been operational for just over 14.5 years with an overall data return of 94.6 percent. The data record for the period November 2013 to October 2014 was good, with total gaps of 15.75 days, equivalent to 95.7 percent data return. The buoy was replaced twice during the reporting period – on 30 March 2014 for regular changeover and on 16 July 2014 due to transmission failure.

On 15 April 2014, Ex-Tropical Cyclone Ita moved offshore near south-east Queensland resulting in a significant wave height (Hsig) of 2.6 m and maximum wave heights (Hmax) of 4.5 m at Mooloolaba. The largest waves for the reporting period occurred during an east coast low pressure system on 23 August resulting in 3.2 m Hsig and 5.5 Hmax. There were no record wave heights during the reporting period that made it in to the top 10 ranking waves (Table 25).

Daily wave recordings (Figure 50) show variability in the peak wave period (Tp) from 4–15 seconds for the recording period. Peak wave direction (Figure 51) was generally from the south to south-east and sea surface temperature ranged from 19° C to 27° C.

The monthly average Hsig fell below a standard deviation (sd) of monthly averages for the entire record during April, June and July. During August the average Hsig was much greater than 1 sd of the whole record due to the two east coast low pressure systems impacting the region (Figure 52).

Percentage exceedance of Hsig (Figure 53) show slightly higher waves occurring throughout summer than winter. The wave climate for the reporting period was generally similar to the entire record except heights of waves occurring less than 5 percent were greater for the entire record than the recent period. Histograms for occurrence of Hsig (Figure 54) show similar wave climate distributions between summer and winter and between the reporting period and the entire record. Histograms of occurrence of Tp (Figure 55) showed a higher occurrence of 7–9 s waves and lower occurrence of 9–11 s waves during summer between the reporting period and all the data. Overall the distribution of Tp was similar to the entire record.

Directional wave rose plots (Figure 57) show a persistent spread of waves from the east to south-east for the reporting period which is very similar to the entire record.

Table 25 Mooloolaba – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	5/03/2004 16:00	5.9	5/03/2004 15:30	12.1
2	28/01/2013 5:30	5.6	28/01/2013 5:00	10.5
3	3/03/2006 6:30	5.3	1/05/2000 18:30	10
4	1/05/2000 19:30	5.1	3/03/2006 6:30	9.2
5	24/08/2007 1:00	5.1	31/12/2007 8:00	8.9

6	30/05/2008 20:30	4.5	24/08/2007 1:30	8.5
7	30/12/2007 22:00	4.4	25/12/2011 7:30	8.4
8	25/12/2011 8:30	4.3	28/06/2012 4:30	7.9
9	28/06/2012 7:00	4.3	2/02/2001 6:00	7.6
10	24/03/2004 5:30	4.1	22/08/2011 13:00	7.6

Table 26 Mooloolaba – Significant meteorological events with threshold Hsig of 2.5m

Date	Hs (m)	Hmax (m)	Tp (s)	Event
26/01/2014 01:00	2.7 (2.8)	4.3 (5.5)	7.8	High pressure system and ridge
15/04/2014 00:30	2.6 (2.8)	4.5 (5.2)	8.6	TC Ita as it moved off-shore with central pressure of 994hPa
23/08/2014 13:30	3.2 (3.4)	5.5 (6.1)	9.3	An east coast low pressure trough with a central pressure of 1017 hPa
28/08/2014 14:00	2.6 (2.7)	4.2 (5.2)	11.0	An east coast low pressure system with a central pressure of 1011 hPa

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.

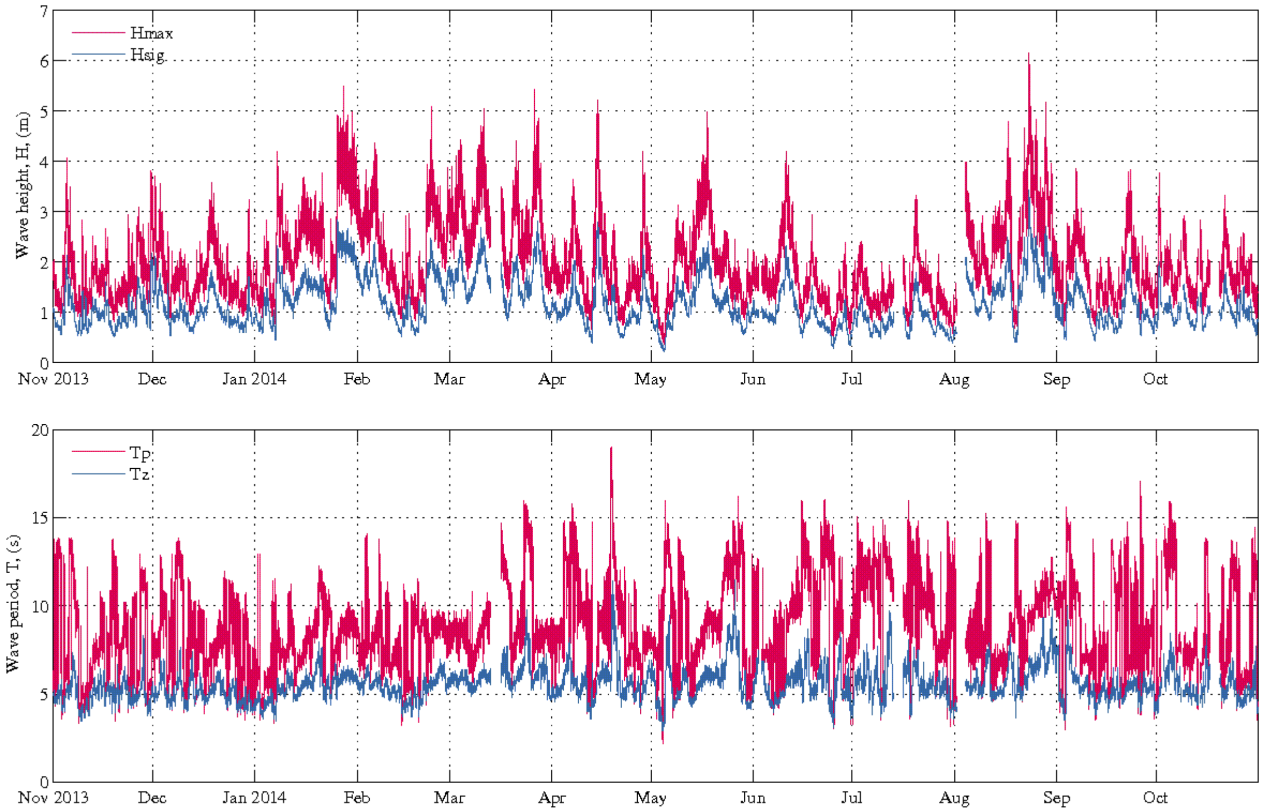


Figure 50 Mooloolaba – Daily wave recordings

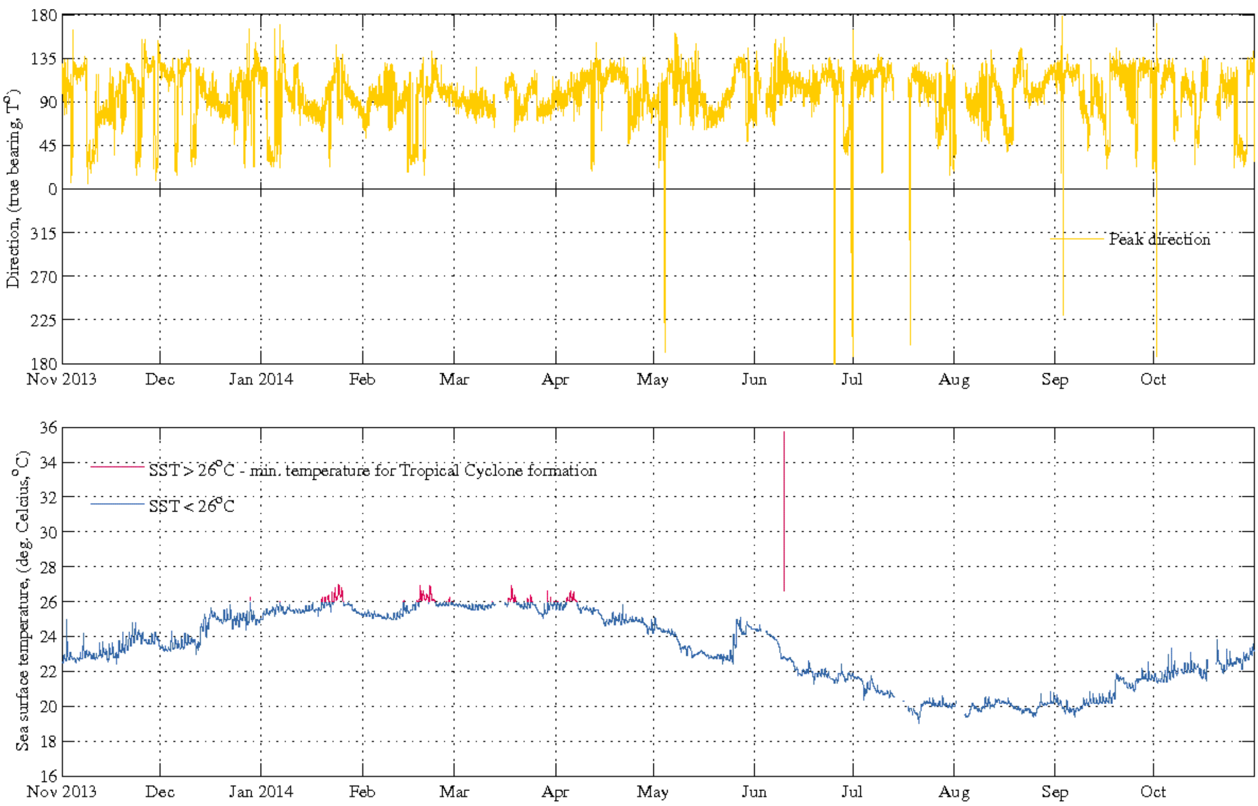


Figure 51 Mooloolaba – Sea surface temperature and peak wave directions

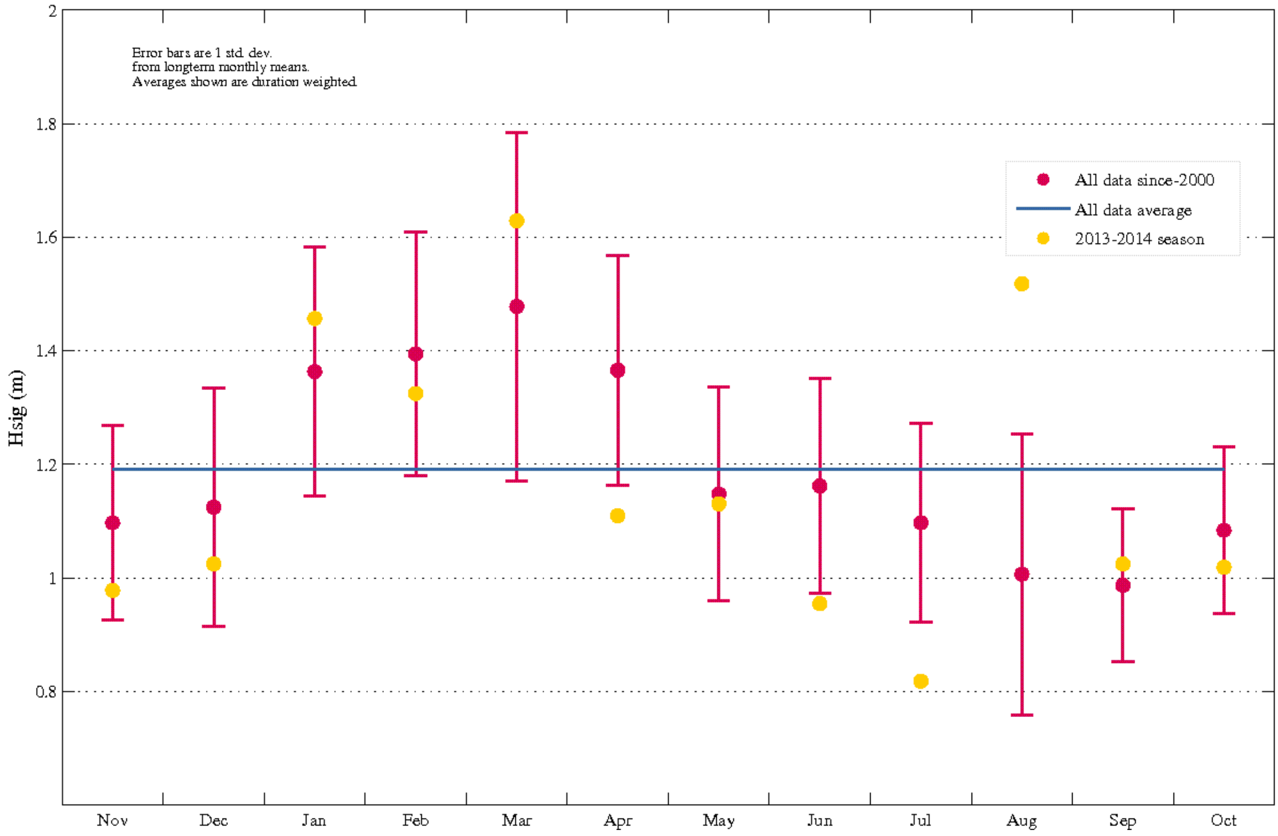


Figure 52 Mooloolaba – Monthly average wave height (Hsig) for seasonal year and for all data

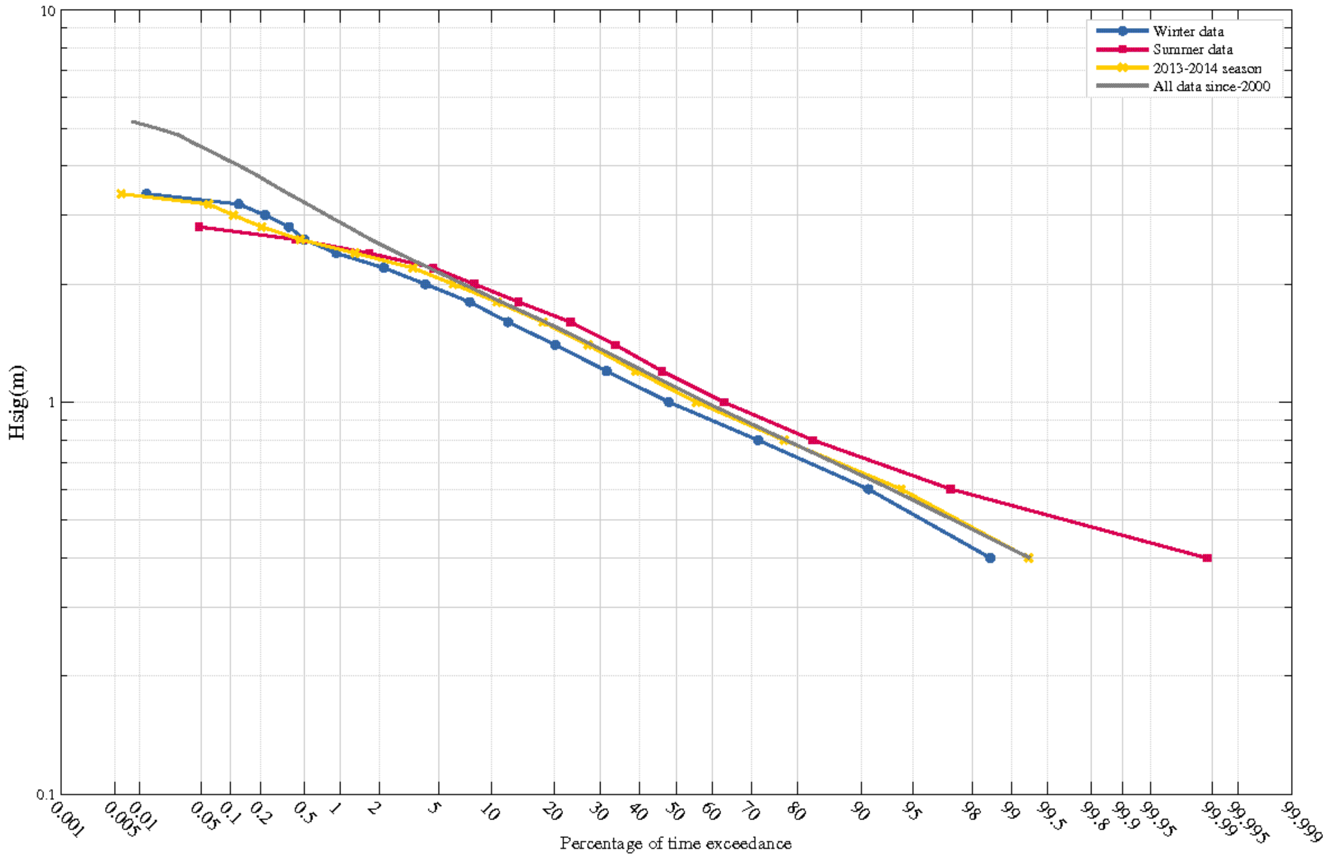


Figure 53 Mooloolaba – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

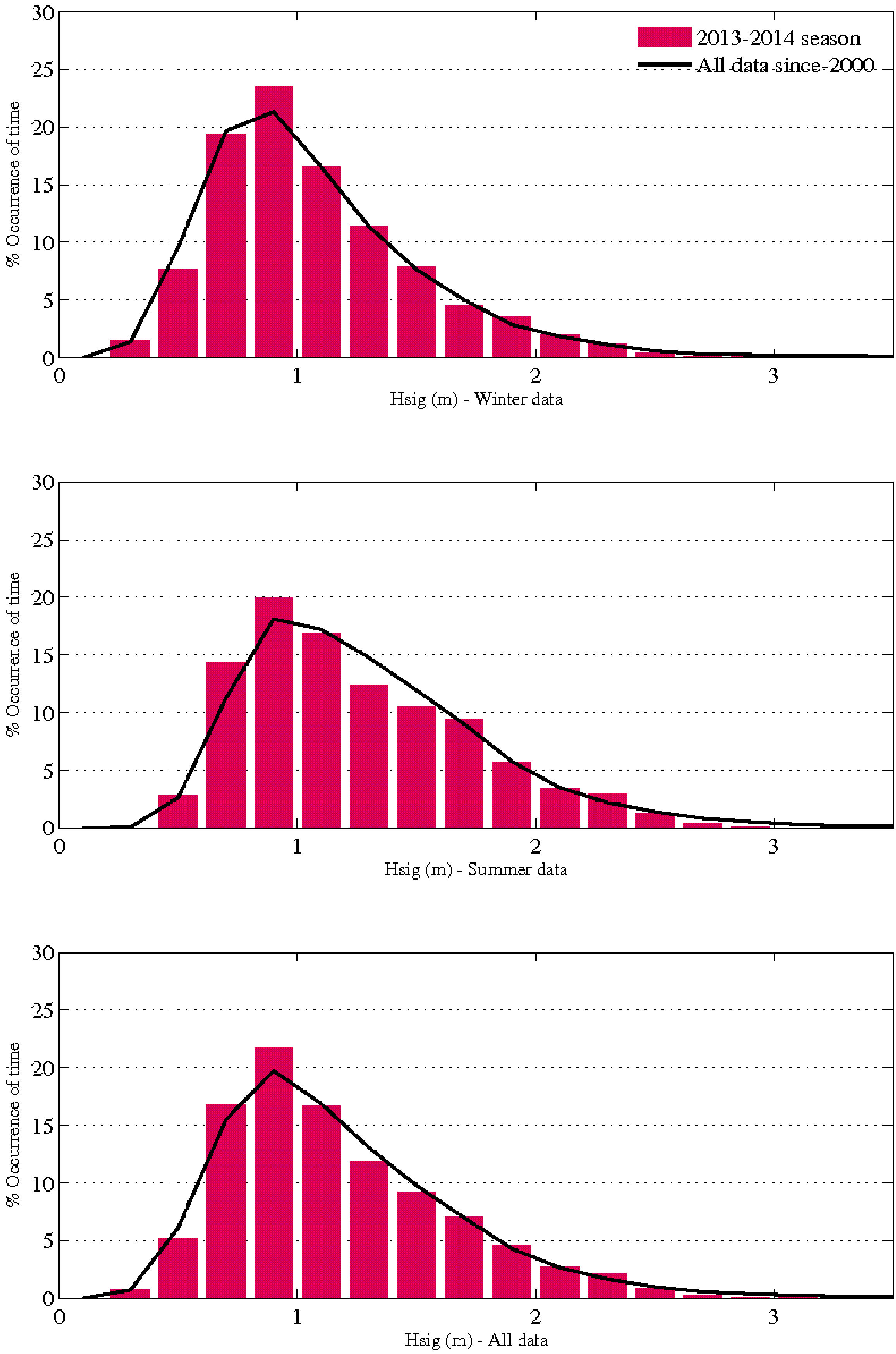


Figure 54 Mooloolaba – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

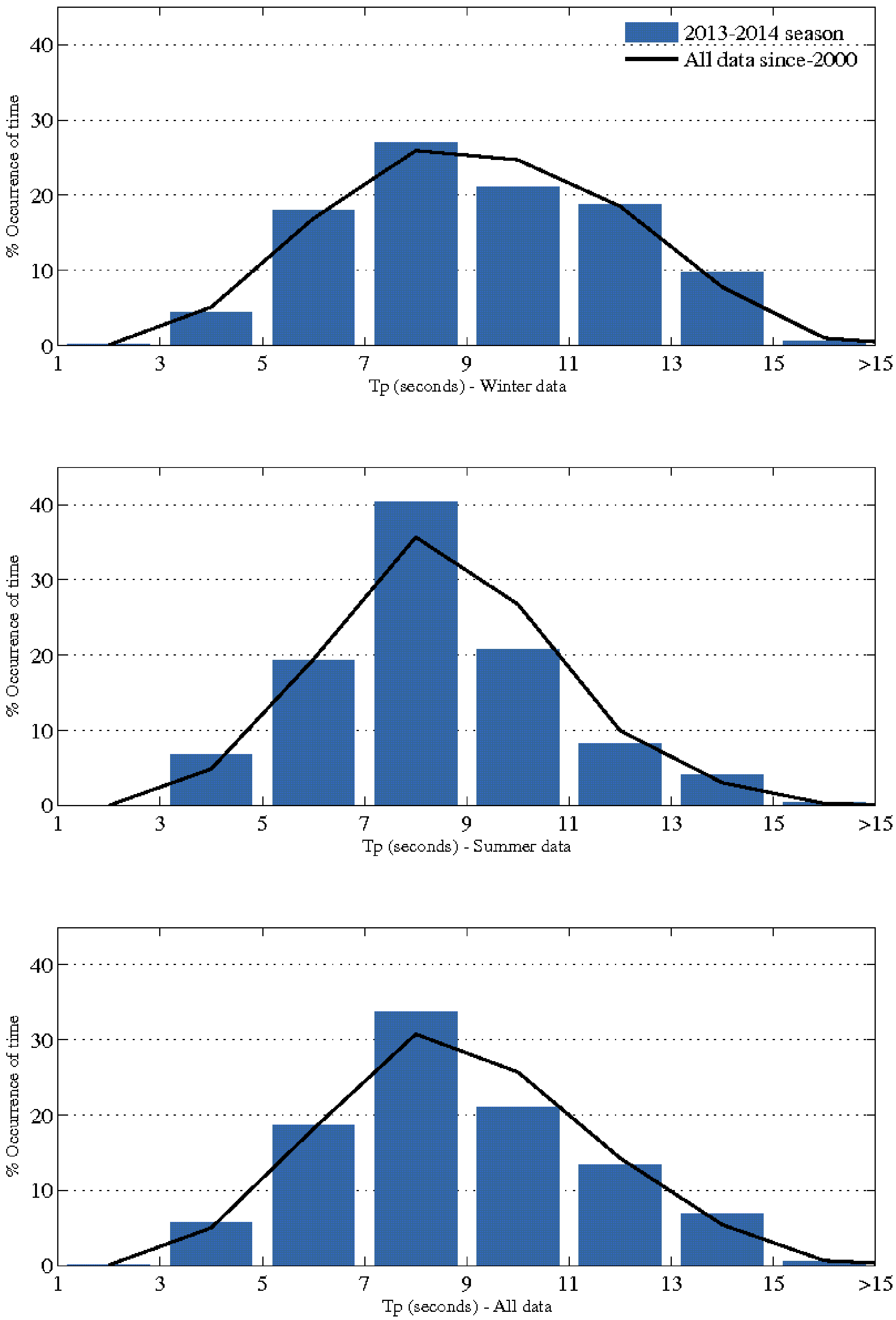


Figure 55 Mooloolaba – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

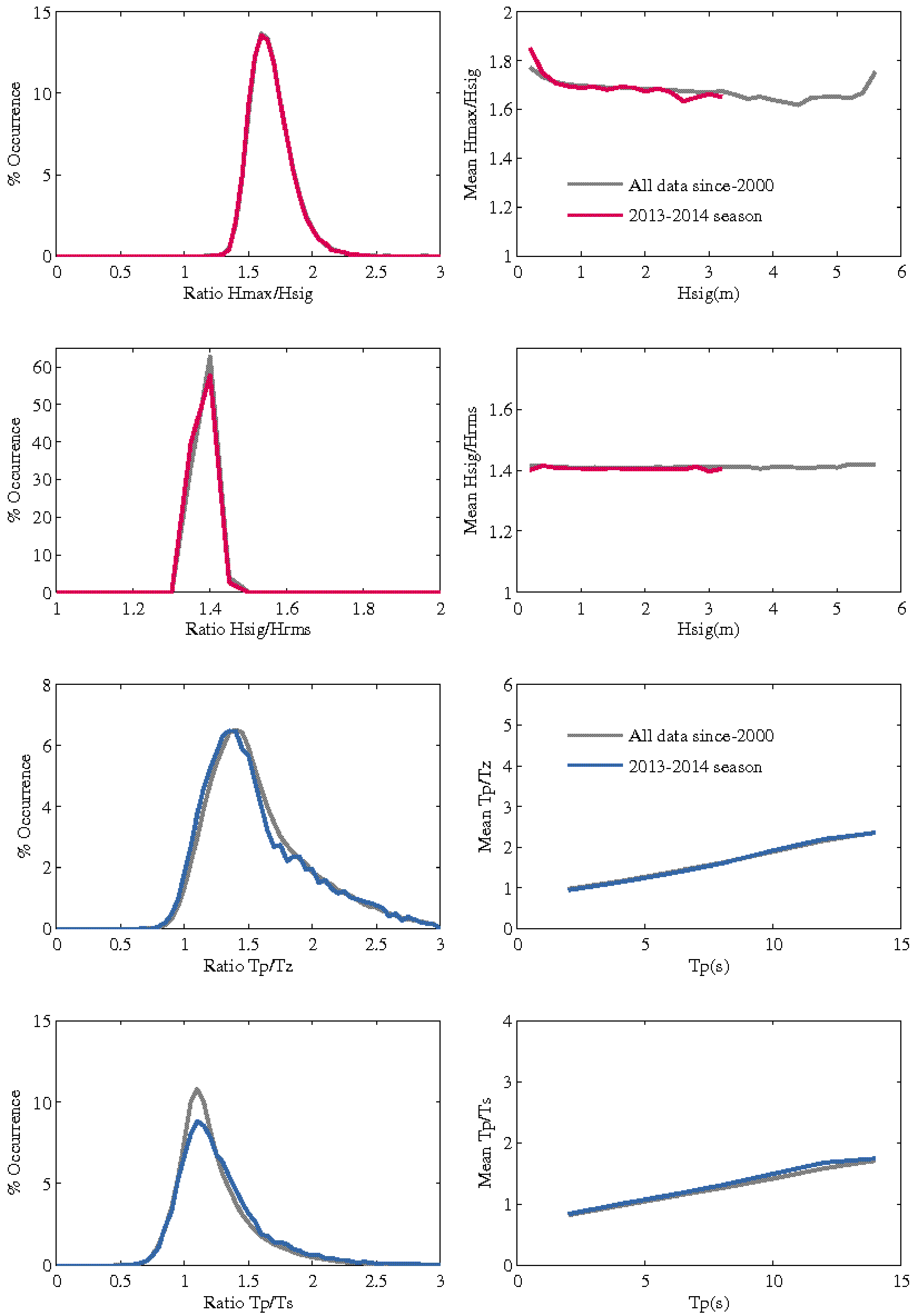


Figure 56 Mooloolaba – Wave parameter relationships

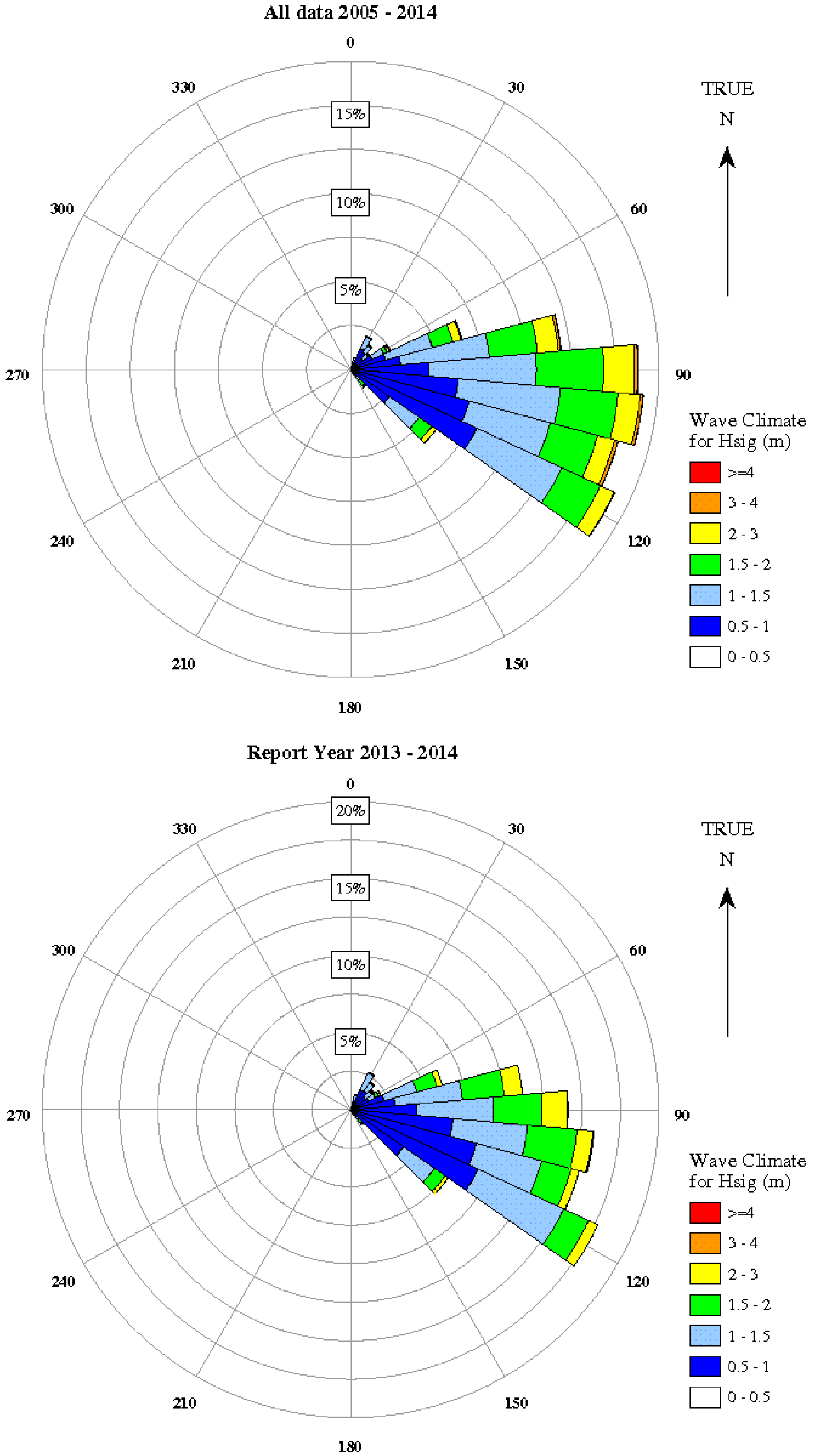


Figure 57 Mooloolaba – Directional wave rose

7.7 Gladstone

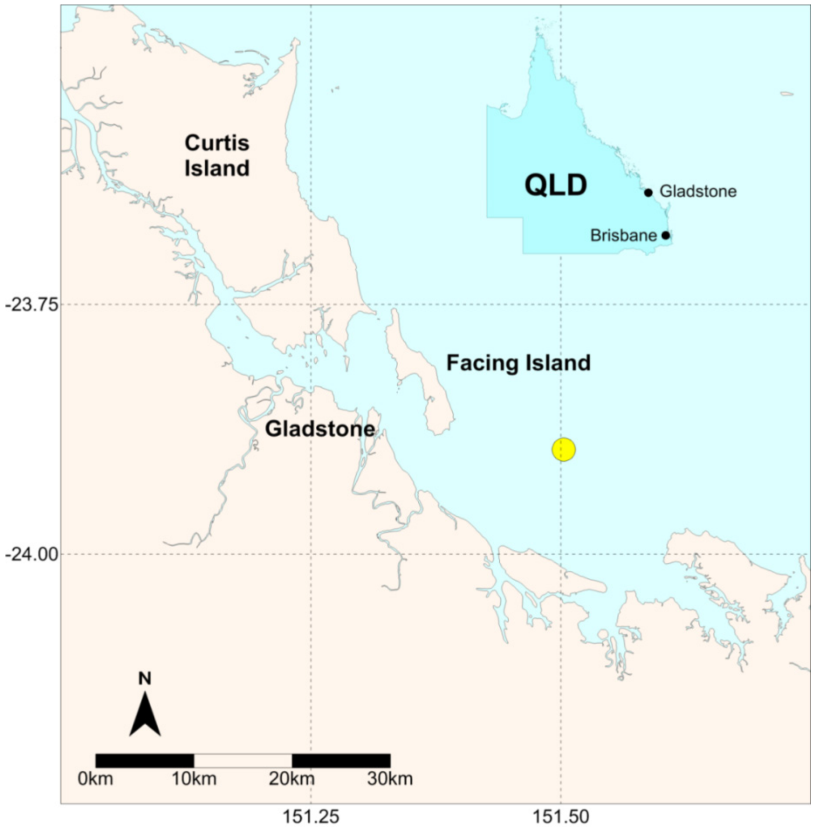


Figure 58 Gladstone – Locality plan

Table 27 Gladstone – wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	23/09/2009	0.14 years	86743	5.11
2013 -14	1/11/2013	2.38 days	17405	1

Table 28 Gladstone – Buoy deployments during the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
23°53.750'S	151°30.122'E	13	2/10/2013	26/09/2014
23°53.695'S	151°30.101'E	16.5	26/09/2014	current

7.7.1

7.7.2 Gladstone – seasonal overview

The Gladstone wave buoy has been operational for just over five years with an overall data return of 97.3 percent. The data record for the period November 2013 to October 2014 was exceptional, with total gaps of only 2.38 days, equivalent to 99.4 percent data return. The buoy was replaced just prior to this reporting period 2 October 2013 and again on 26 September 2014 (Table 28).

There were two significant wave heights (Hsig) during the reporting period that made it into the top ten ranks (Table 29) and two maximum wave heights (Hmax) that also made the top ten ranking. Notably, a Hsig of 2.8 m was reported during the passage of Tropical Cyclone Dylan and ranked third, while a Hmax of 6.0 m was also reported on the same day and ranked second. The relatively short record means that the highest top ten ranked waves should be exceeded.

TC Dylan made land-fall just south of Bowen as a category 2 tropical cyclone. Despite passing so far north of Gladstone, Dylan had a massive influence over the wave climate with 4.4 m maximum wave height sustained for over three hours. The wave period was not directly influenced by the passage of Dylan.

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

The wave climate during the reporting period was very similar to the wave climate of the whole record, evidenced in the percentage time exceedance (Figure 62) and histograms of the occurrence of Hsig and Tp (Figure 63 and Figure 64). It is worth noting that the ratios between different wave parameters such as Hmax/Hsig were consistent between this reporting period and all of the historic data, the exception being the ratio between Hsig/Hmax and Hsig/Hrms where the influence of TC Dylan pushed Hsig out to 3 m, these are plotted in figure 65.

The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean with the exception of four months: January, April, July and August. During these months the mean was higher than the mean +1 sd. The passage of TC Dylan was responsible for the increase in the average monthly Hsig in January, see figure 59.

The plot of wave direction over the 2013–14 season (Figure 60) showed a dominant easterly (slightly north of east) direction with an occasional swing to the North, mostly during winter. The dominance of incident wave direction is reflected in the directional wave rose plot (Figure 66) along with the most common wave height (Hsig) of 0.5 m to 1.0 metres.

The temperature (SST) measured in the buoy hull showed a seasonal high over 28° C. The SST from December to the beginning of March was generally warm enough for Tropical Cyclone development but fell below the 26° C threshold temperature for the remaining nine months. The lowest SST occurred mid-July where it fell to 18° C. The SST from 26 September to the end of October is not correct, calibration of the sensor failed prior to deployment. This data should not be used for any purpose.

Table 29 Gladstone – Highest waves

Rank	Date	Hs (m)	Date	Hmax (m)
1	1/02/2010 20:00	3.2	1/02/2010 20:00	6.1
2	25/01/2013 02:00	3.2	1/02/2014 1:00	6.0
3	01/02/2014 1:00	2.8	25/01/2013 14:00	5.8
4	20/03/2010 10:30	2.3	20/03/2010 21:30	4.7
5	16/01/2012 22:00	2.3	16/01/2012 22:30	4.5
6	12/04/2013 04:00	2.3	12/04/2013 05:00	3.9
7	12/10/2010 12:00	2.2	12/10/2010 11:00	3.8
8	13/03/2010 13:30	2.1	13/03/2010 14:00	3.8
9	08/01/2014 22:00	1.9	8/01/2014 22:00	3.2

Table 30 Gladstone – Significant meteorological events with threshold Hsig of 2.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
8/01/2014 22:00	2.0 (1.9)	3.3 (3.2)	7.3	Low pressure trough extending south from the Gulf of Carpentaria into Victoria.
1/02/2014 1:00	2.5 (2.8)	4.4 (6.0)	8.4	The passage of TC Dylan, 30 January through 1 February 2014.

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.

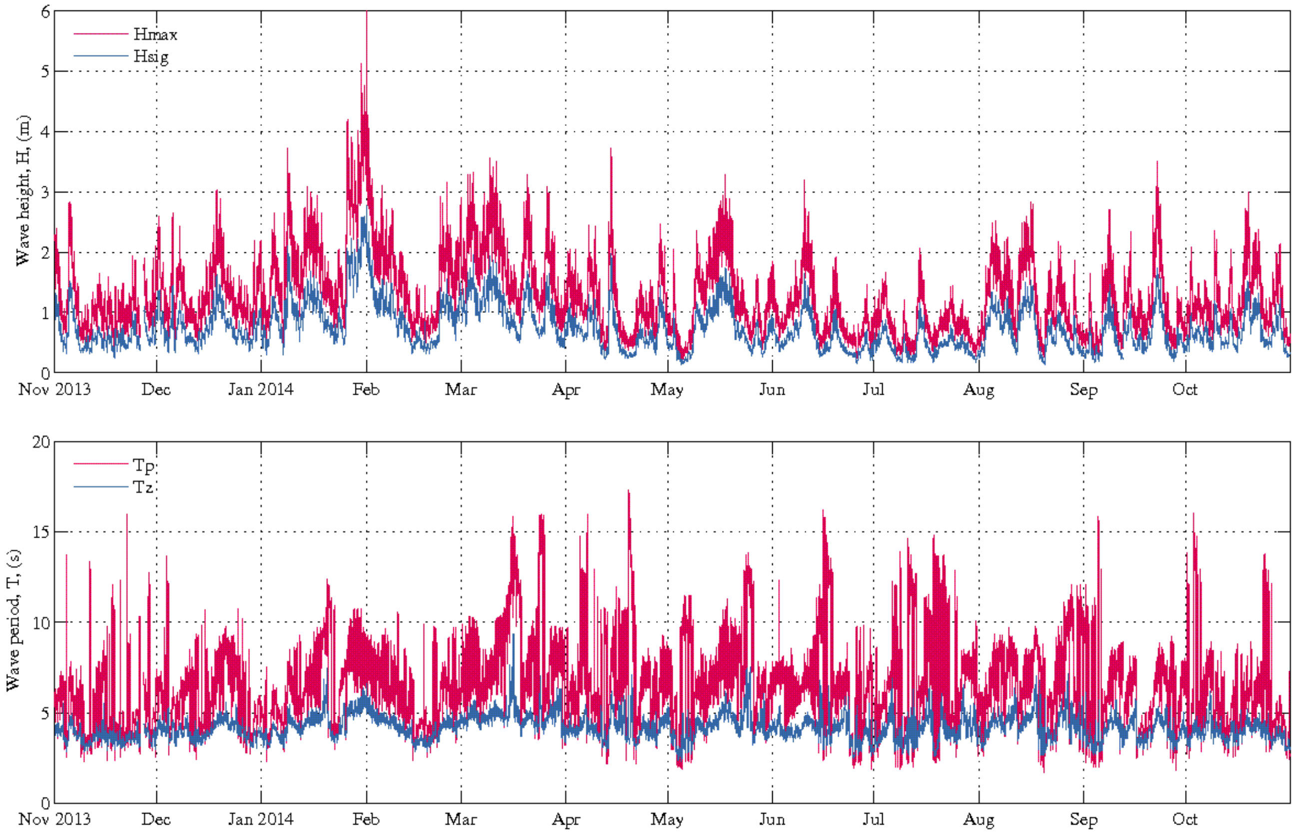


Figure 59 Gladstone – Daily wave recordings

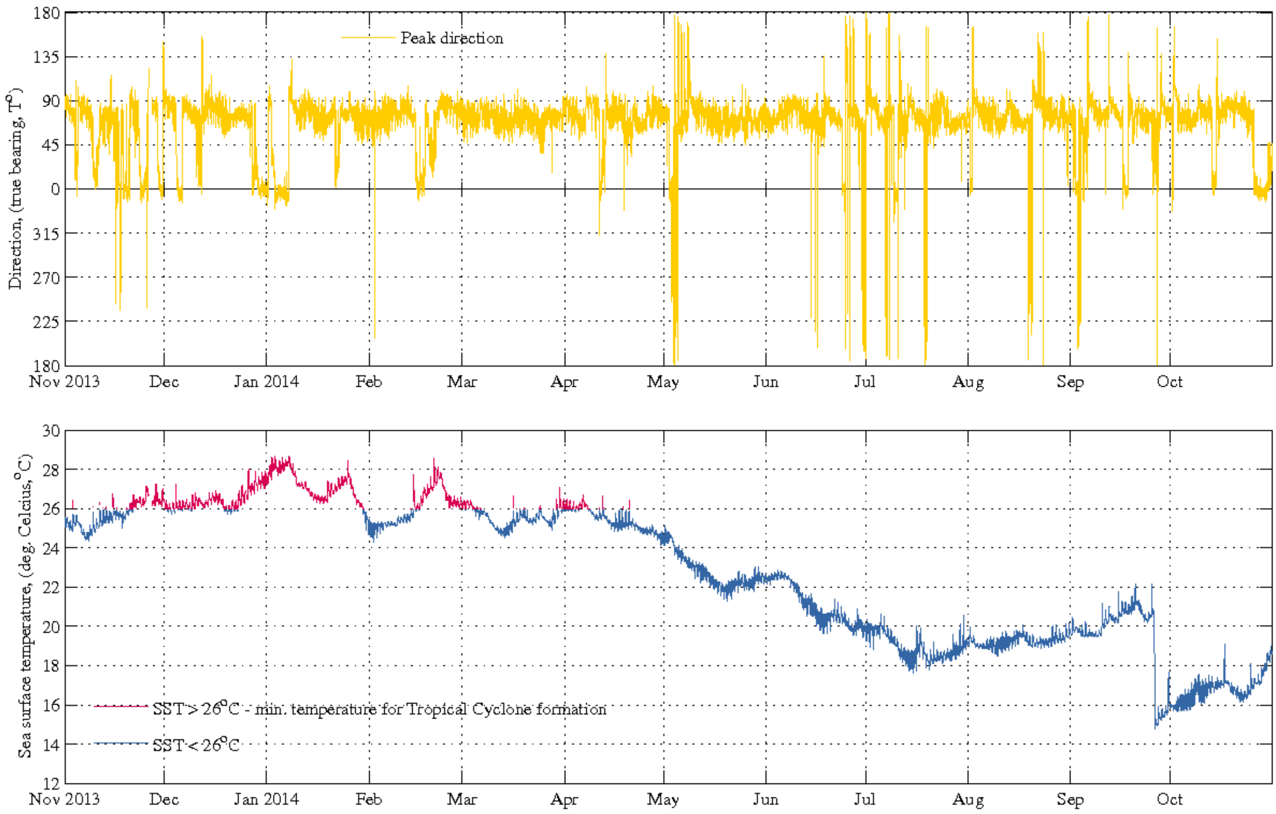


Figure 60 Gladstone – Sea surface temperature and peak wave directions

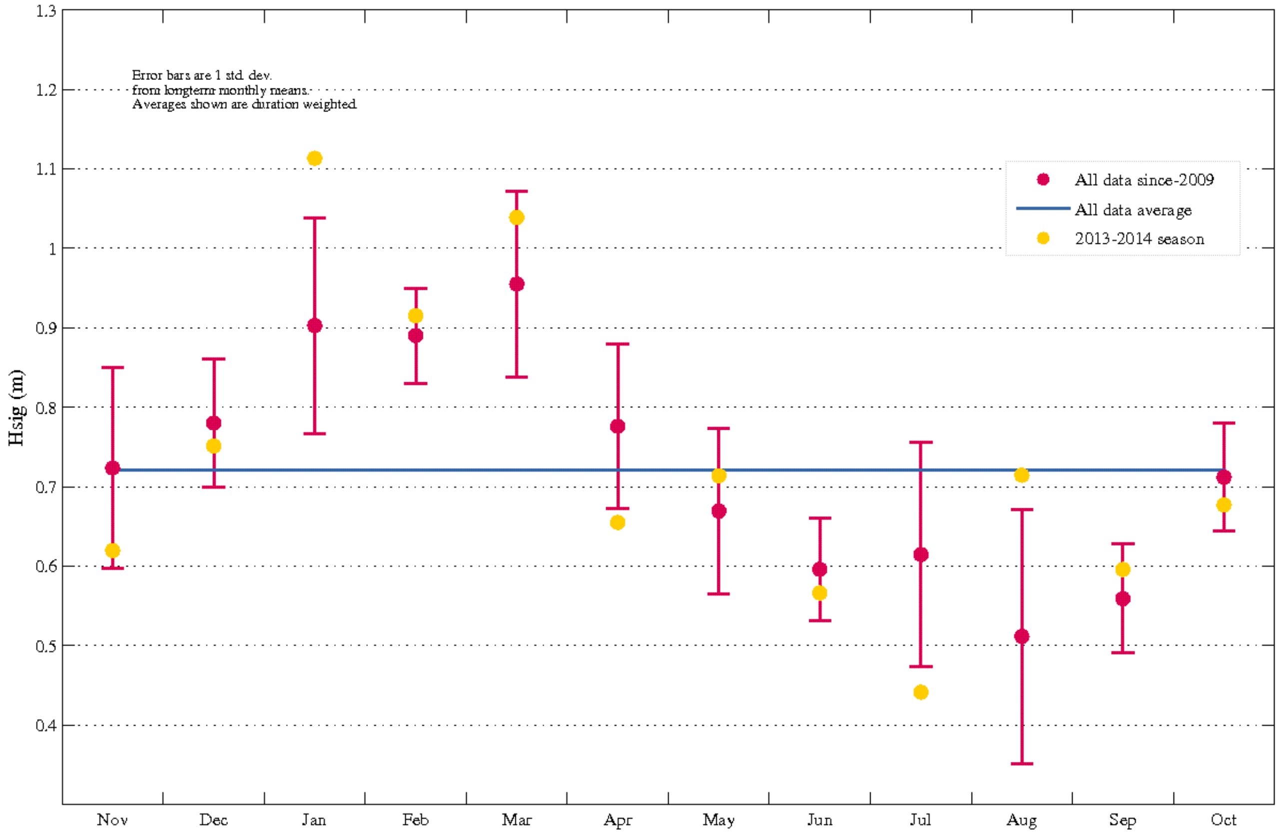


Figure 61 Gladstone – Monthly average wave height (Hsig) for seasonal year and for all data

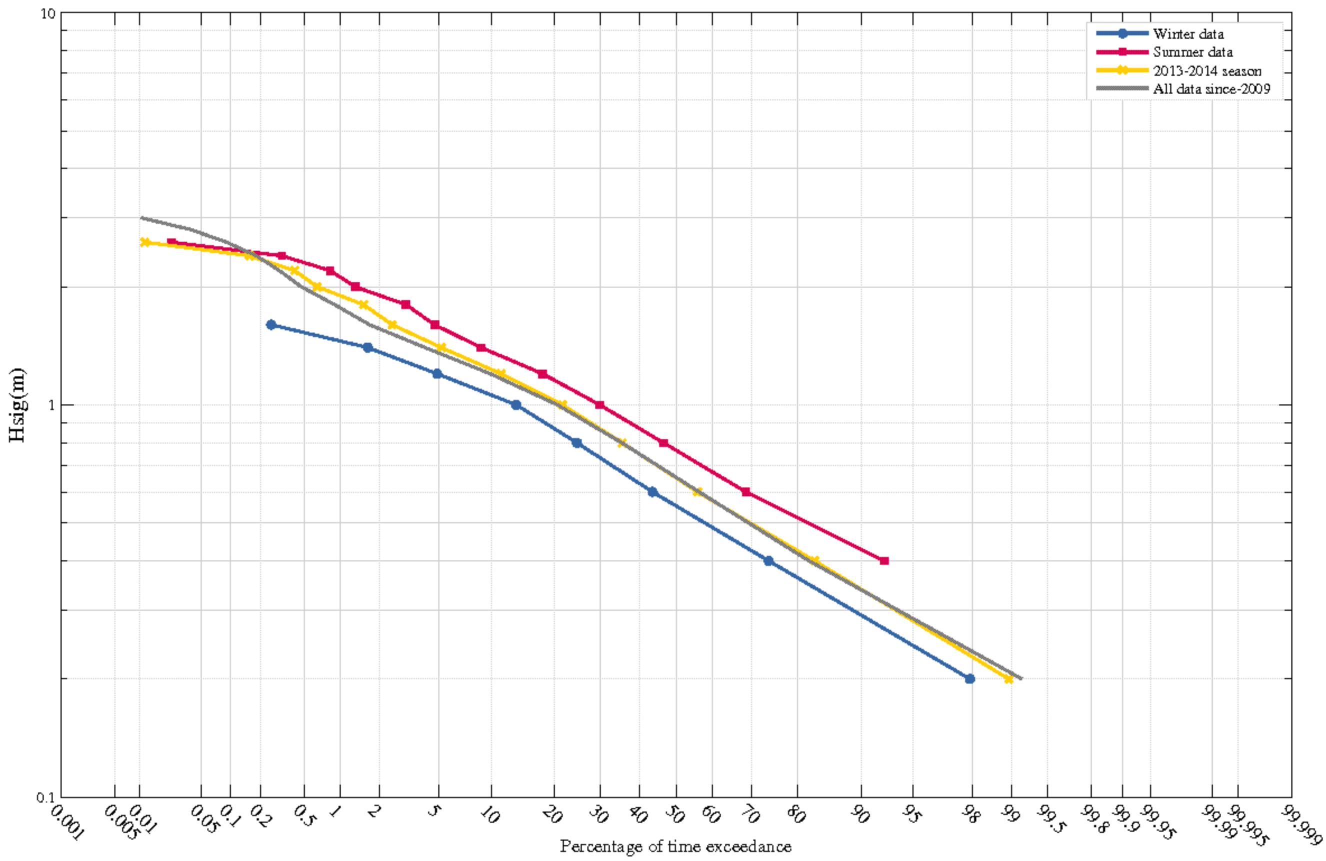


Figure 62 Gladstone – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

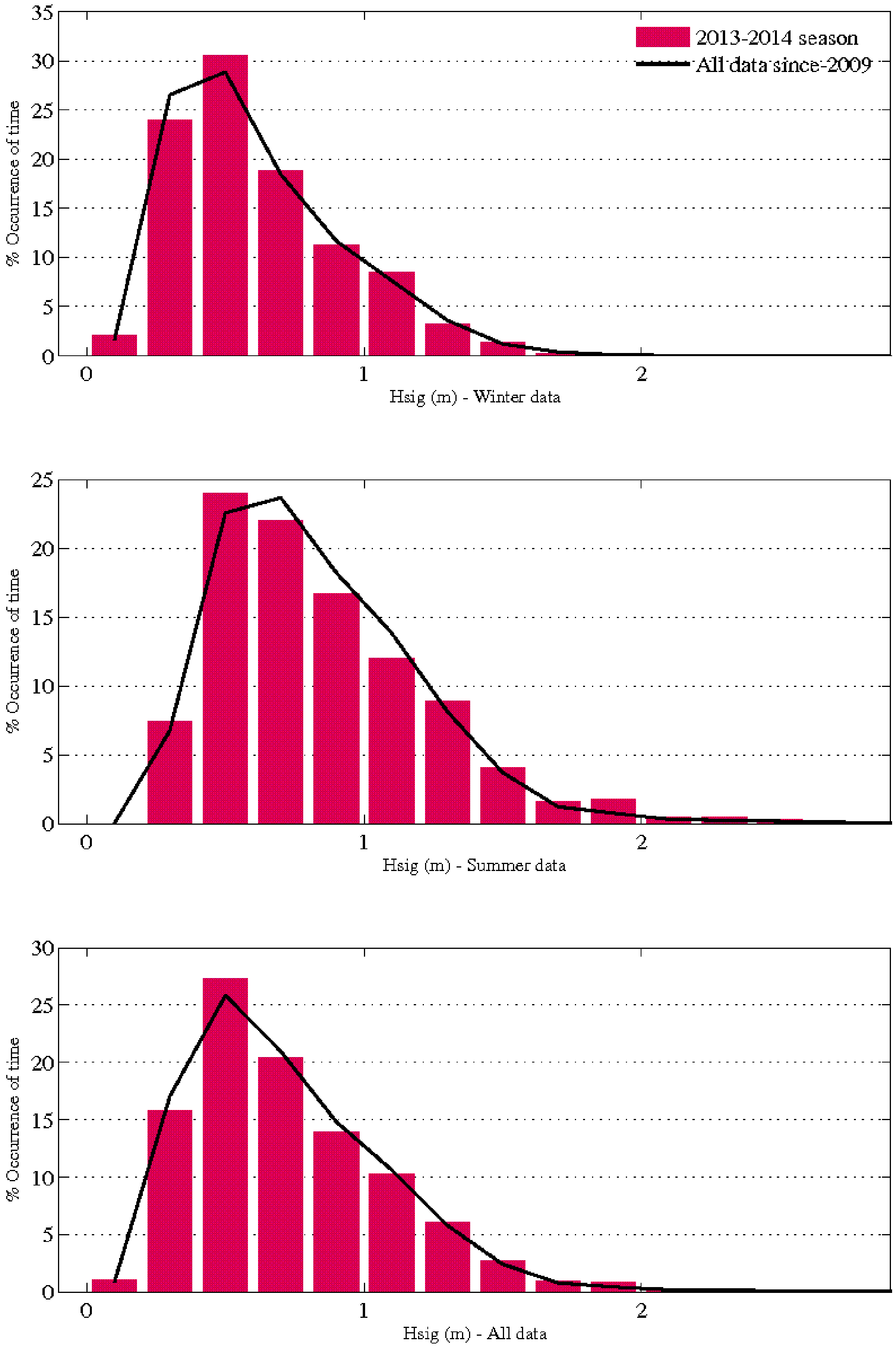


Figure 63 Gladstone – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

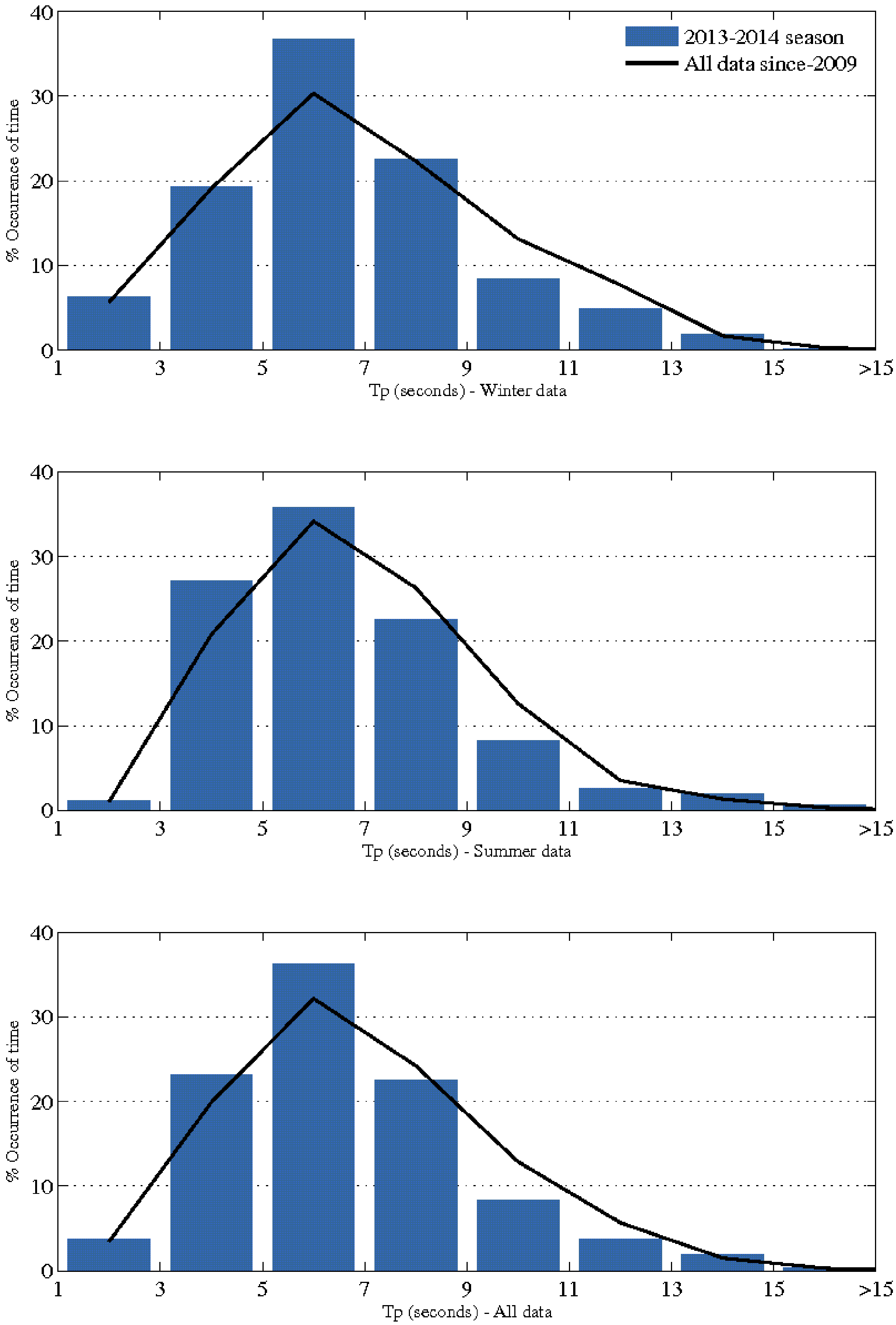


Figure 64 Gladstone – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

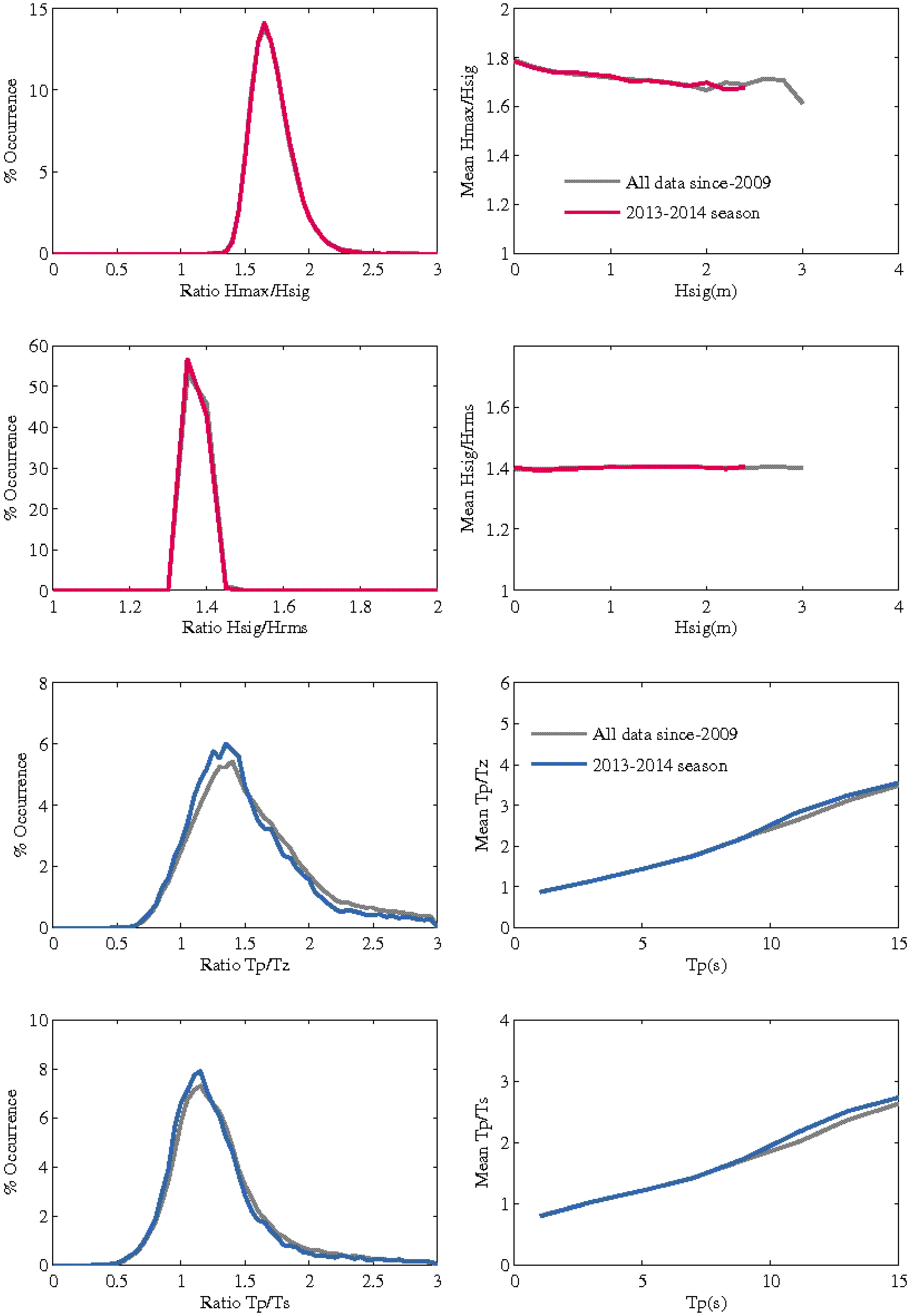
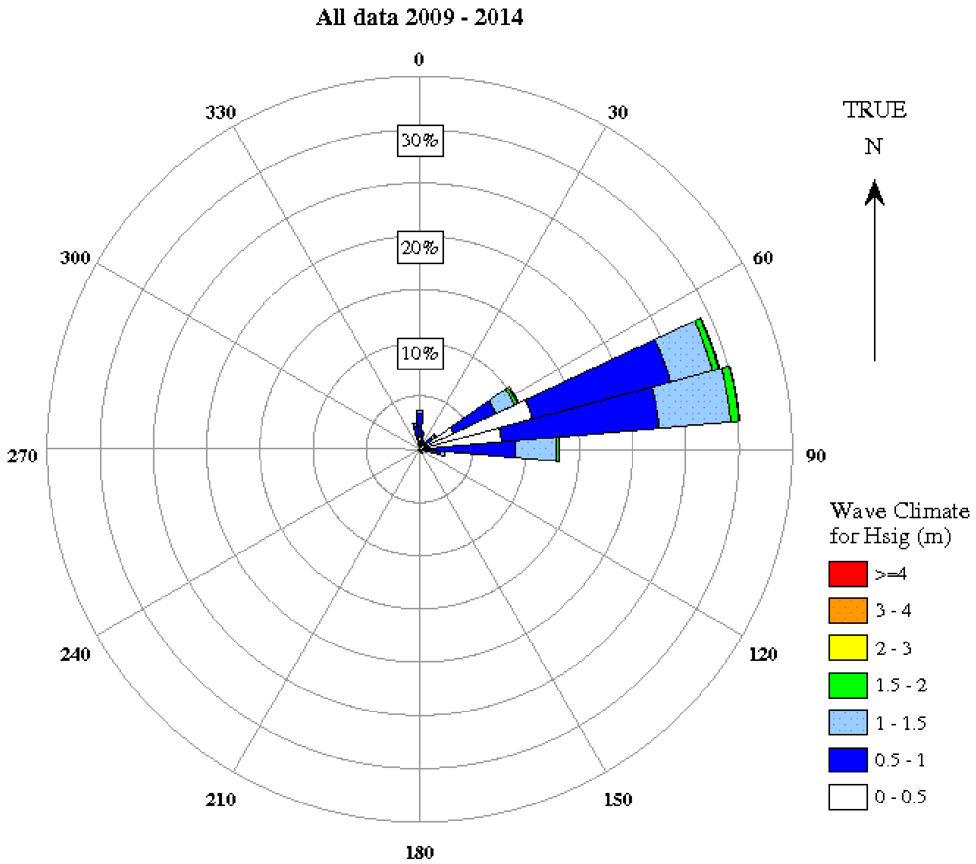


Figure 65 Gladstone – Wave parameter relationships



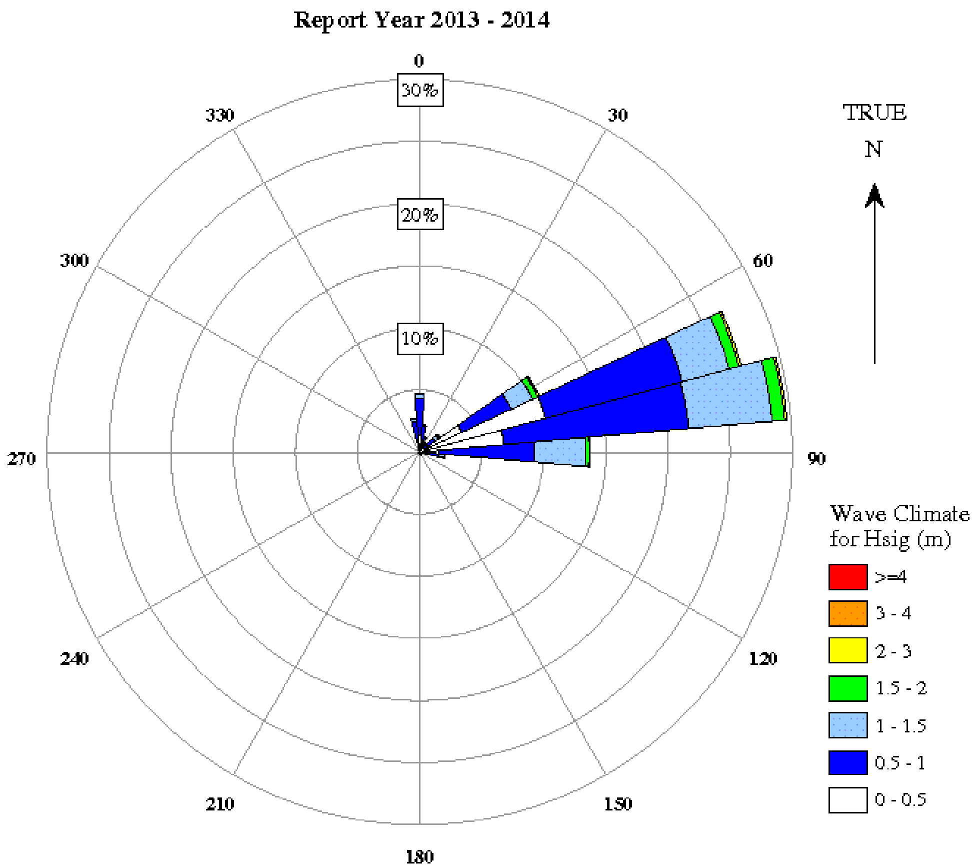


Figure 66 Gladstone – Directional wave rose

7.8 Emu Park

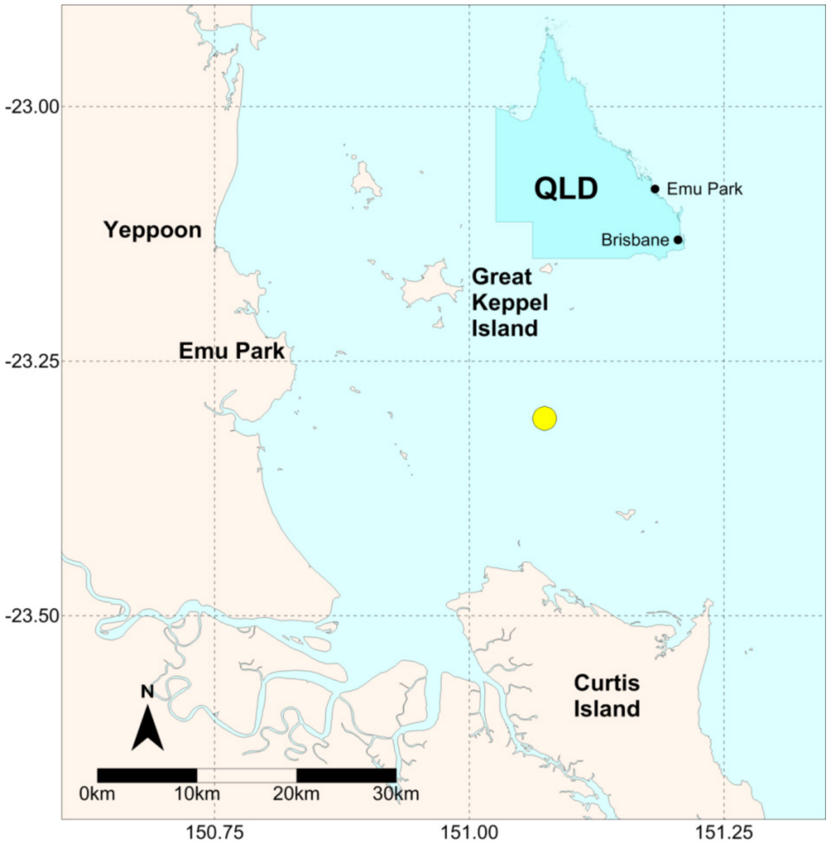


Figure 6731 Emu Park – Locality plan

Table 32 Emu Park – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/07/1996	0.90 years	253624	18.6
2013 -14	1/11/2013	10.50 days	17015	1

Table 33 Emu Park – Buoy deployments during the 2013-14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°18.385'S	151°04.388'E	10	26/10/2012	23/05/2014
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 18 years with an overall data return of 95.2 percent. The data recorded for the period November 2013 to October 2014 was good, with total gaps of 10.5 days, equivalent to 97.1 percent data return. The buoy was replaced once during the reporting period on 23 May 2014 (Table 33).

The third highest significant wave height (Hsig) and the fourth highest maximum wave height (Hmax) were recorded on 31 January during Ex-TC Dylan. Hsig and Hmax reached 3.2 m and 5.5 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. Sea surface temperature (SST) ranged from 19.5° C to 29° C (Figure 69). SST was high enough for tropical cyclone development throughout summer except for extended periods in November, February and March.

The monthly average Hsig was outside of one standard deviation (sd) during January, April, July and August (Figure 70) during the reporting period. January was influenced by a low combined with a trough early on (Table 35), as well as TC Dylan towards the end of the month consequently exceeding 1 sd for average Hsig. Even with the impact on increased wave heights from TC Ita during April, average Hsig for the month was outside of a negative sd. Transmission failure for an extended period during July is likely to have caused average Hsig to fall below 1 sd of the record.

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 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 5–7 second Tp during winter, this range being the most common period for the reporting period.

Directional wave rose plots (Figure 75) show dominant incident waves from the east and a very similar distribution for the reporting period and entire record.

Table 34 Emu Park – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	25/01/2013 11:00	3.9	1/02/2010 3:30	8.2
2	1/02/2010 2:00	3.7	25/01/2013 11:30	7.4
3	31/01/2014 1:30	3.5	9/03/1997 11:30	6.9
4	28/08/1998 6:30	3.2	31/01/2014 4:00	6.7
5	4/06/2002 13:00	3.2	28/08/1998 8:00	6.4

6	9/03/1997 19:30	3.1	4/06/2002 17:30	6.4
7	20/03/2010 16:00	3	20/03/2010 12:30	5.9
8	9/03/2009 1:30	3	4/03/2003 11:30	5.9
9	23/04/2000 20:30	3	26/02/2010 1:00	5.9
10	31/05/2008 6:00	2.9	18/02/2008 14:30	5.8

Table 35 Emu Park – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
8/01/2014 22:30	2.5 (2.6)	4.1 (5.0)	7.1	A low [1006 hPa] and trough present in central Queensland
31/01/2014 1:00	3.2 (3.5)	5.5 (6.7)	7.9	Ex-Tropical Cyclone Dylan [996 hPa] and a trough were present around central Queensland.
14/04/2014 9:00	2.5 (2.9)	4.3 (5.0)	7.5	Tropical Cyclone Ita [994 hPa] tracked from north to south along the east Queensland coast.

Denotes peak Hsig event

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

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

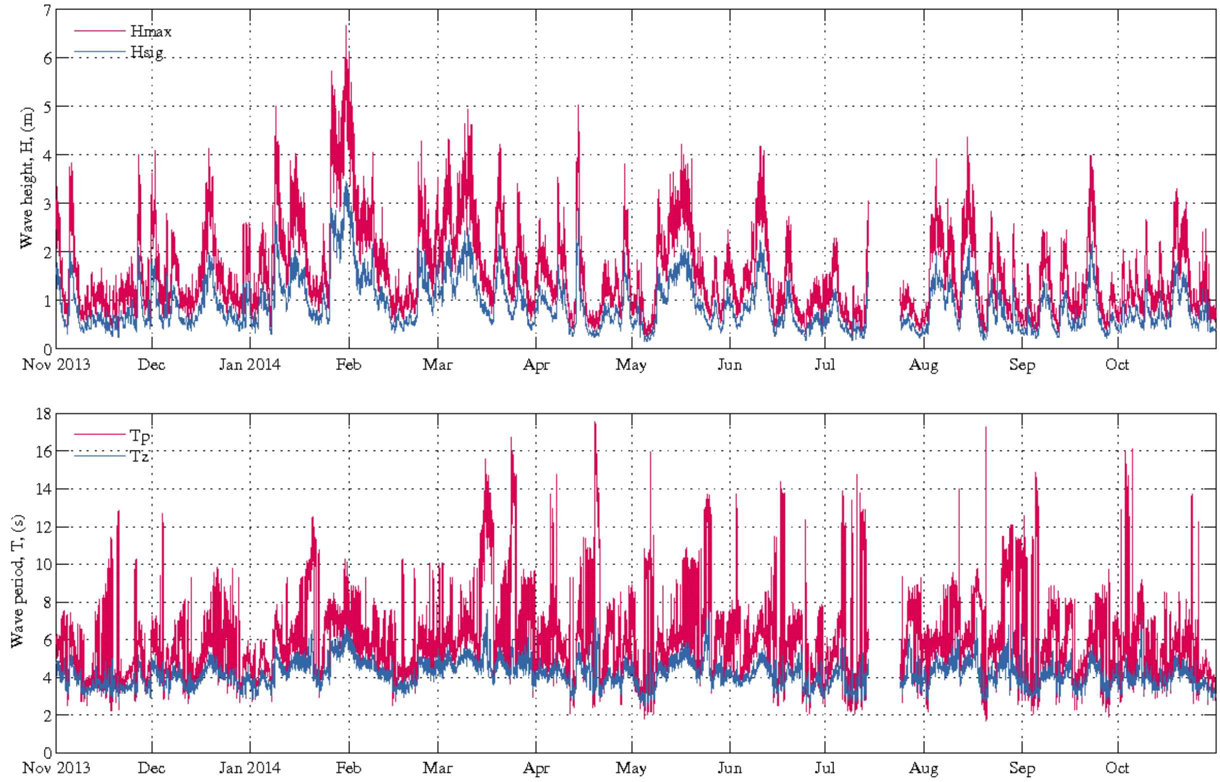


Figure 68 Emu Park – Daily wave recordings

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

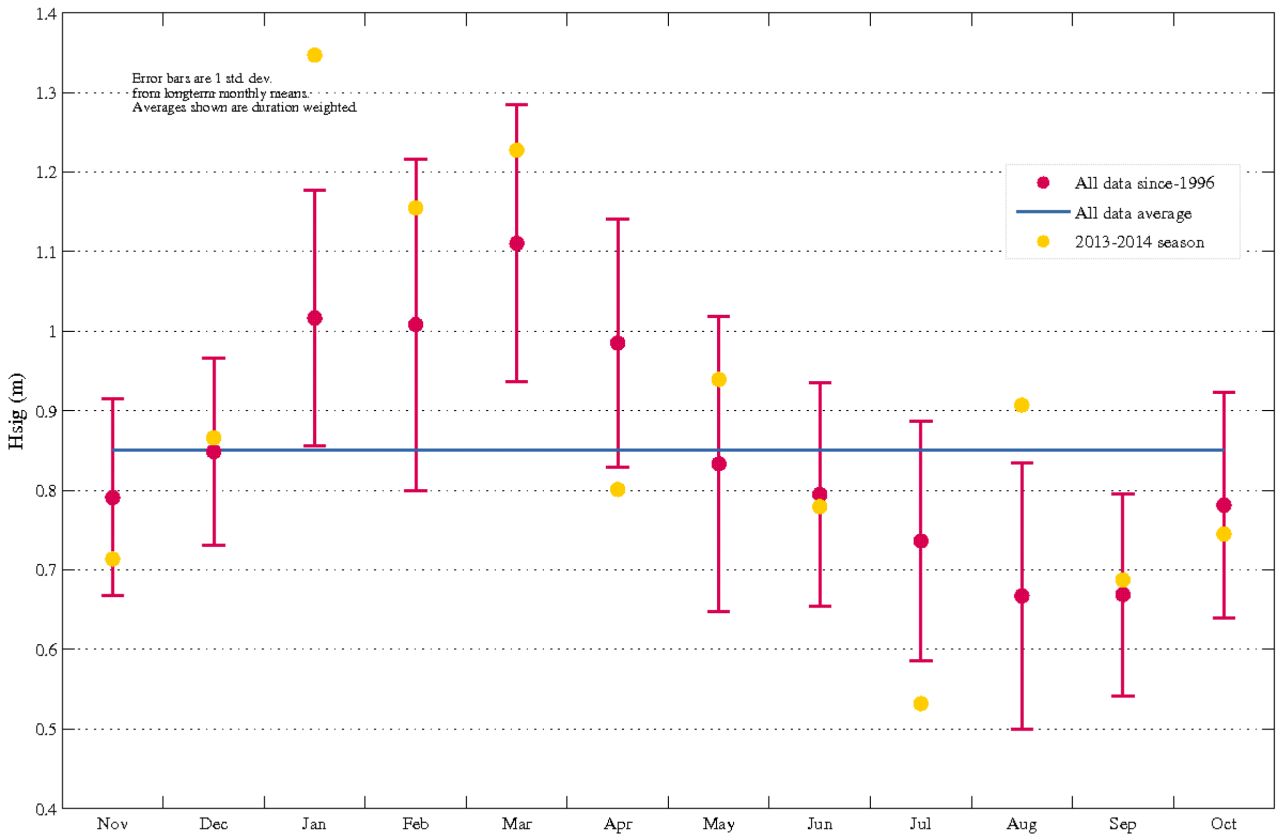


Figure 70 Emu Park – Monthly average wave height (Hsig) for seasonal year and for all data

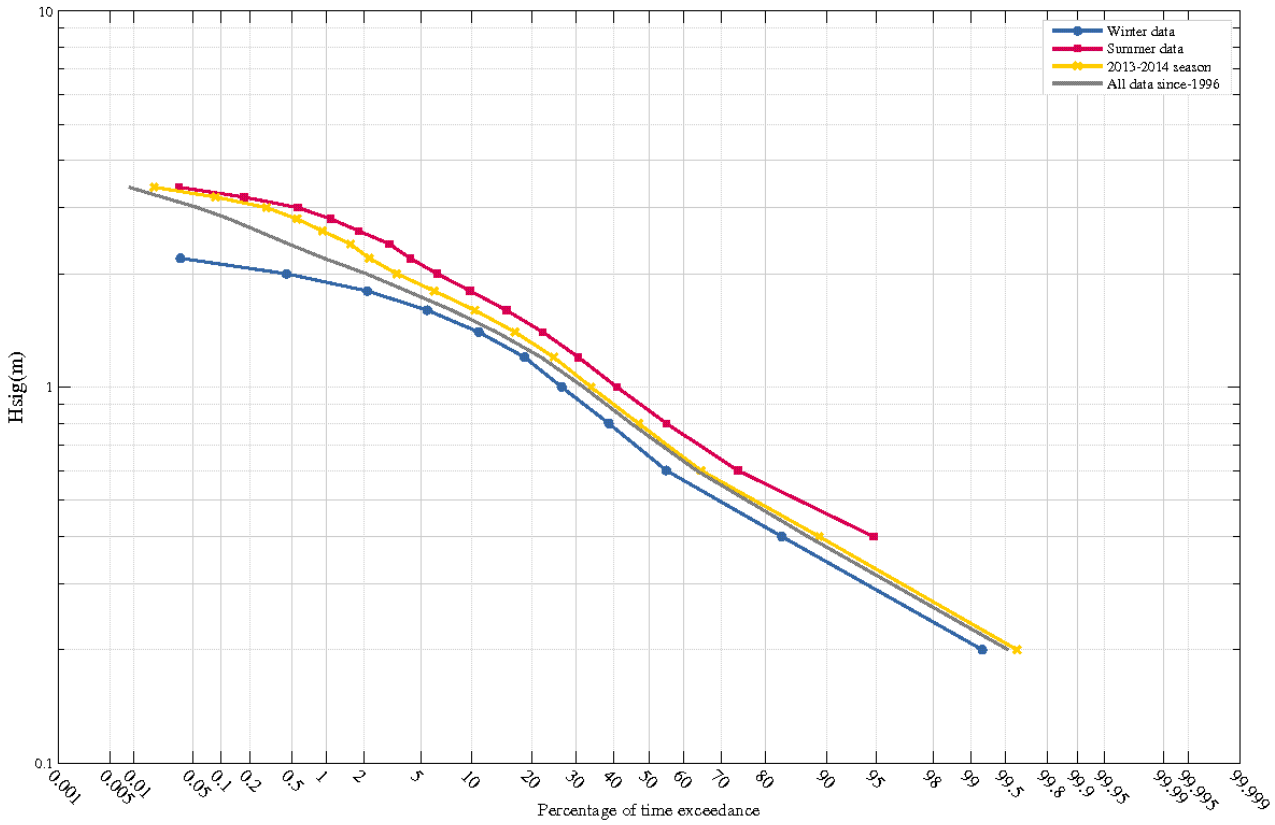


Figure 71 Emu Park – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

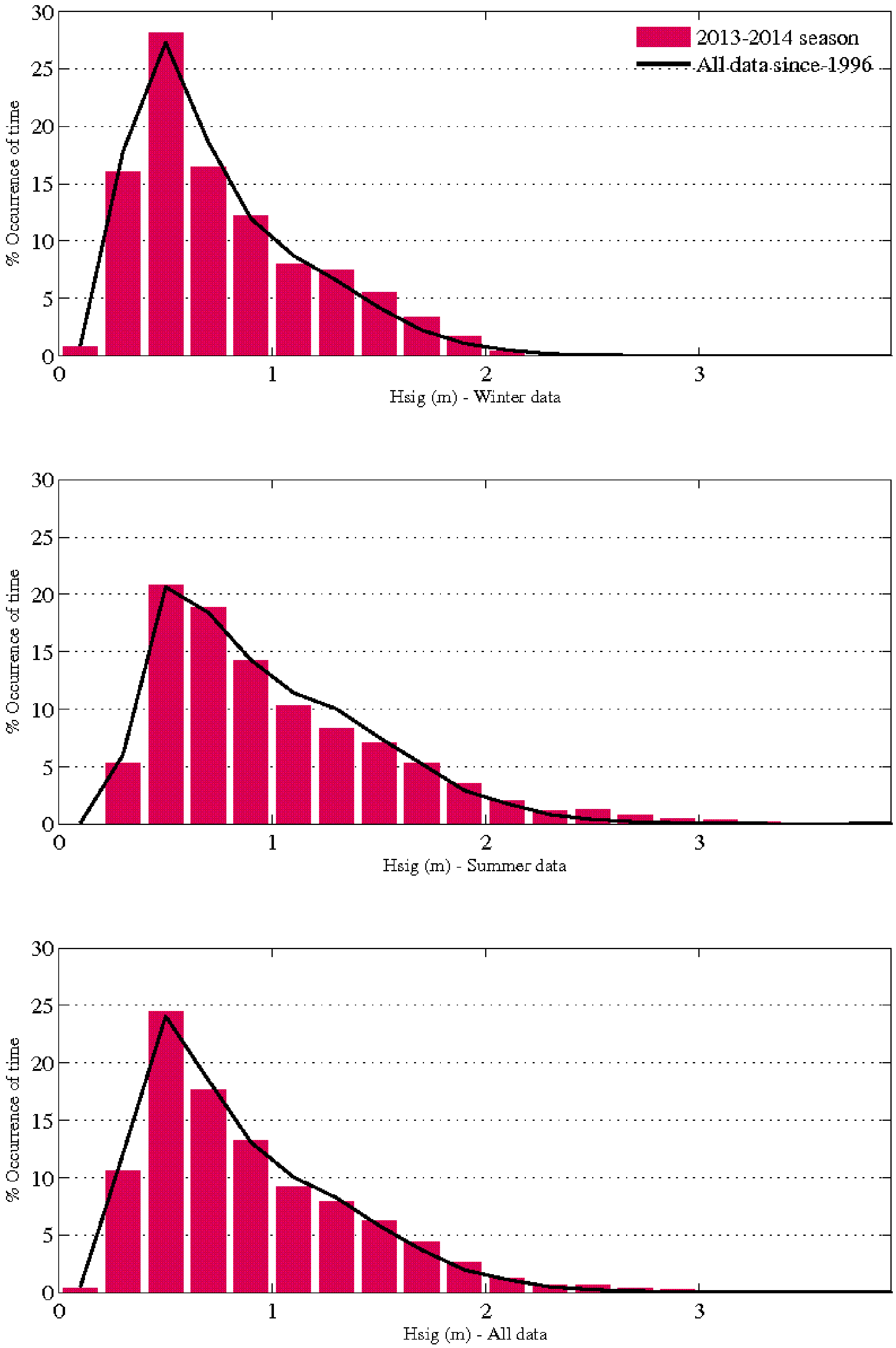


Figure 72 Emu Park – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

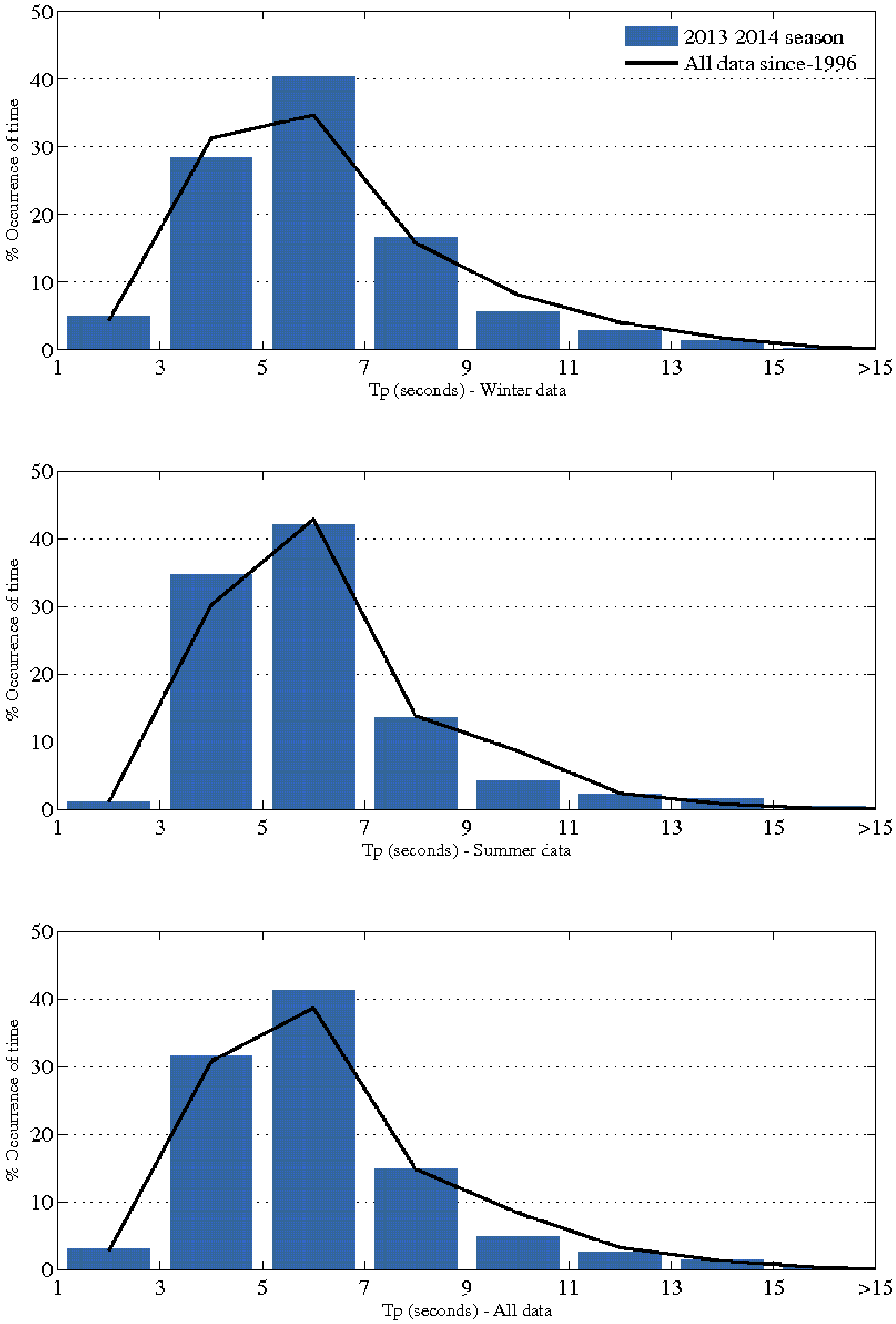


Figure 73 Emu Park – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

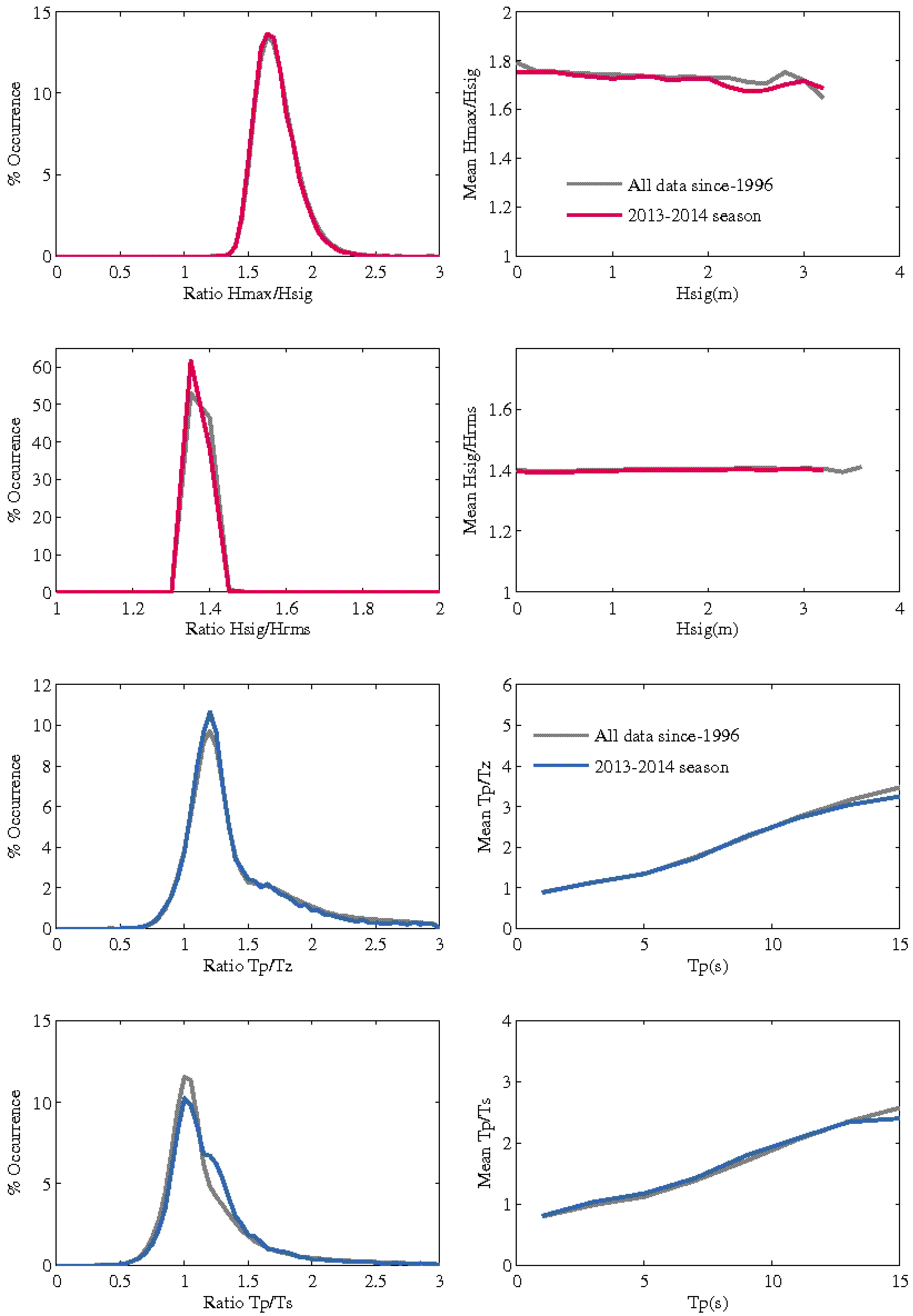
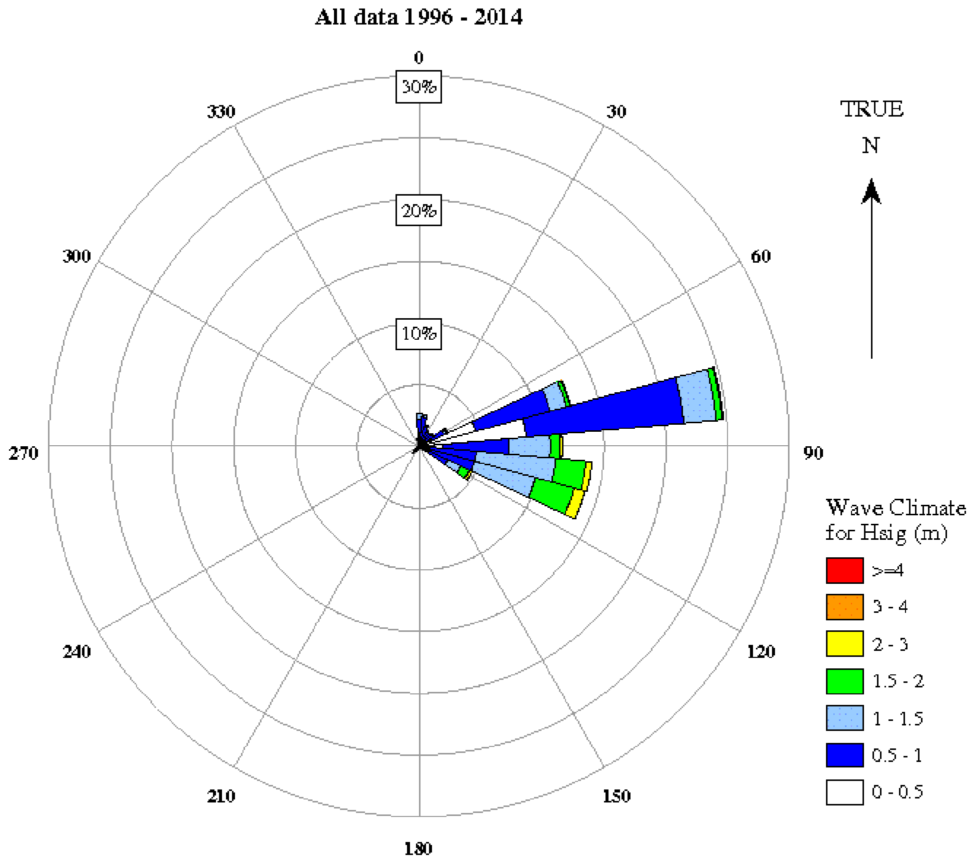


Figure 74 Emu Park – Wave parameter relationships



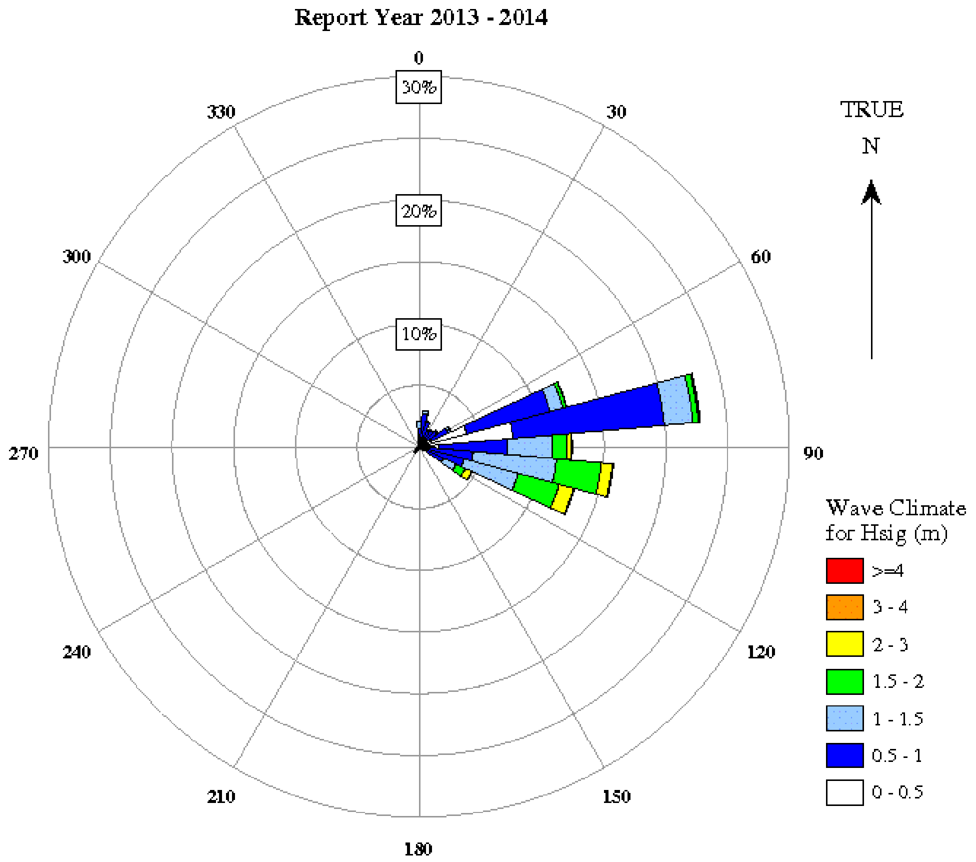


Figure 75 Emu Park – Directional wave rose

7.9 Hay Point

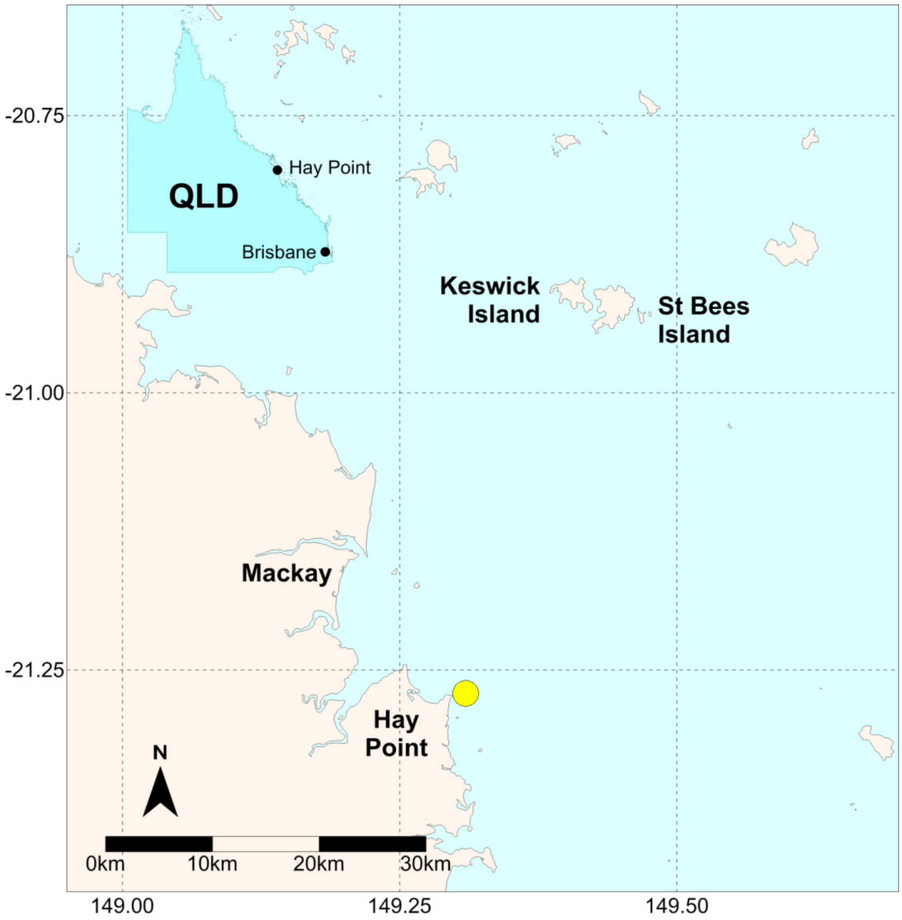


Figure 76 Hay Point – Locality plan

Table 36 Hay Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	24/04/1977	11.7 years	324497	37.6
2013 -14	1/11/2013	0.67 days	17487	1

Table 37 Hay Point – Buoy deployments for the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°16.266'S	149°18.586'E	10	21/11/2012	23/03/2014
21°16.270'S	149°18.586'E	10	23/03/2014	current

7.9.1 Hay Point – seasonal overview

The Hay Point wave buoy has been operational for just over 37.5 years. The data record for the period of November 2013 to October 2014 was exceptional, with total gaps of only 0.67 days, equivalent 99.8 percent data return. The buoy was replaced once during the reporting period on 23 April 2014 (Table 46).

The largest waves occurred during January of the reporting period during TC Dylan resulting in the second highest significant wave height (Hsig) and the highest maximum wave height (Hmax) recorded at the site (Table 47). The influence of TC Dylan and TC Hadi (Table 48) 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. Sea surface temperature (SST) ranged from 18°C to 30°C (Figure 78) and was high enough for tropical cyclone development for the summer months except for periods during February and March.

The monthly average Hsig generally fell within one standard deviation (sd) of the long term mean with the exception of November and January (Figure 79). November experienced smaller waves resulting in a mean Hsig more than -1 sd below the long term monthly average TC Dylan impacted the area in January contributing to the above average recorded wave height for the month.

Percentage 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.

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 38 Hay Point – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	21/03/2010 1:30	4	30/01/2014 22:00	7.0
2	30/01/2014 22:00	3.7	10/03/1997 10:00	6.8
3	9/03/1997 20:00	3.1	21/03/2010 4:30	6.3
4	31/01/2010 7:30	2.8	24/02/1996 2:00	5.6
5	16/02/2008 17:30	2.8	17/02/2008 21:00	5.4
6	1/02/1978 3:00	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 0:30	5
9	1/02/2007 22:30	2.4	22/03/1994 19:00	4.8
10	3/05/2000 5:30	2.4	3/03/2004 21:00	4.7

Table 39 Hay Point – Significant meteorological events with threshold Hsig of 2.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
30/01/2014 22:00	3.3 (3.7)	6.0 (7.0)	9.2	Tropical Cyclone Dylan [990 hPa] formed northeast of Townsville on January 30 and made landfall as a category 2 on the morning of January 31 near Bowen.
9/03/2014 21:00	2.1 (2.2)	3.5 (4.2)	6.9	A low over the Coral Sea moved southwest towards Mackay intensifying to become Tropical Cyclone Hadi [992 hPa] on 10 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.

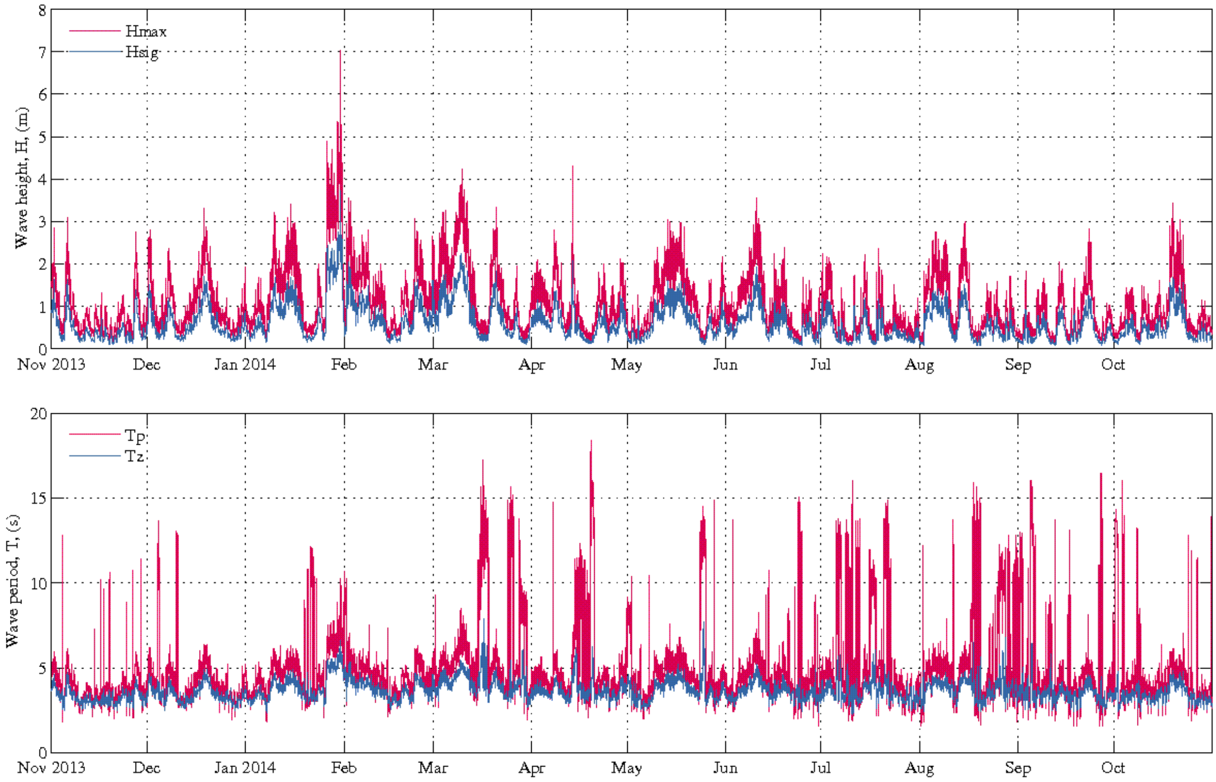


Figure 77 Hay Point – Daily wave recordings

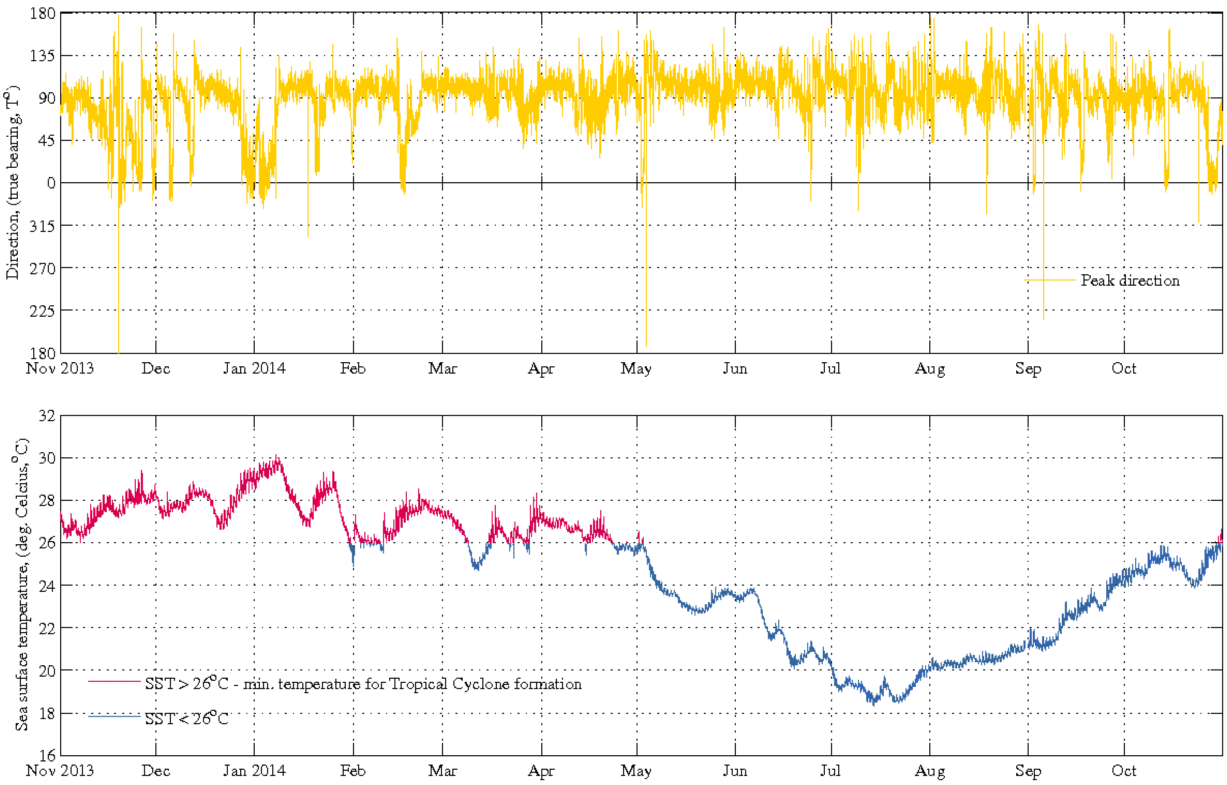


Figure 78 Hay Point – Sea surface temperature and peak wave directions

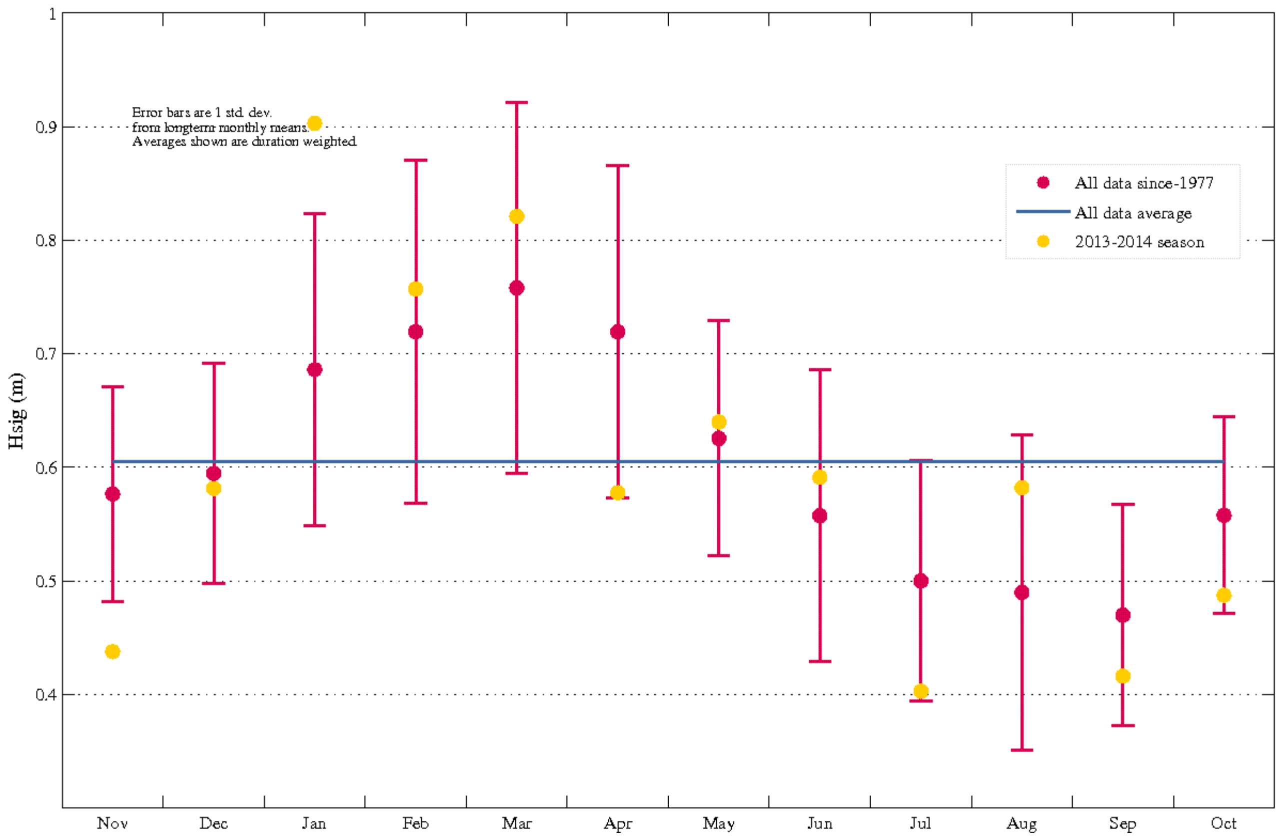


Figure 79 Hay Point – Monthly average wave height (Hsig) for seasonal year and for all data

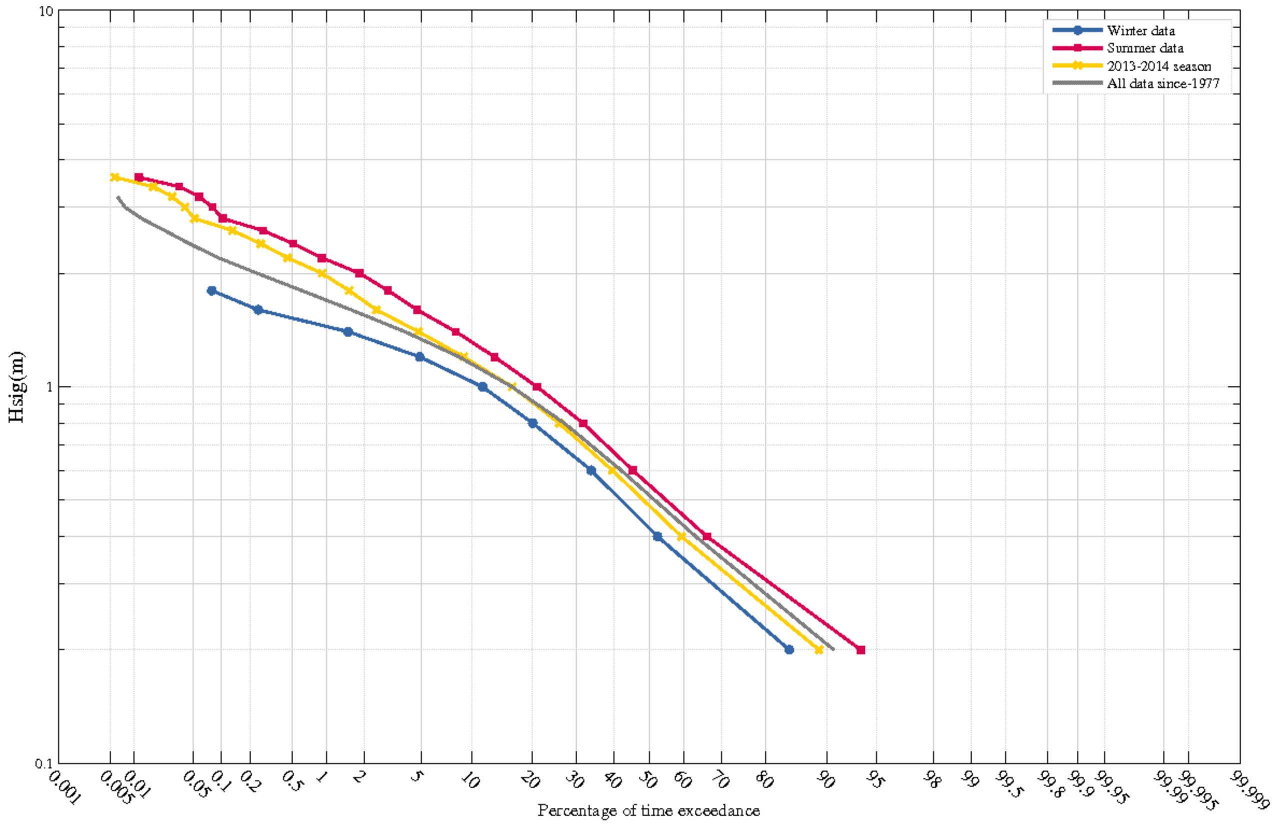


Figure 80 Hay Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

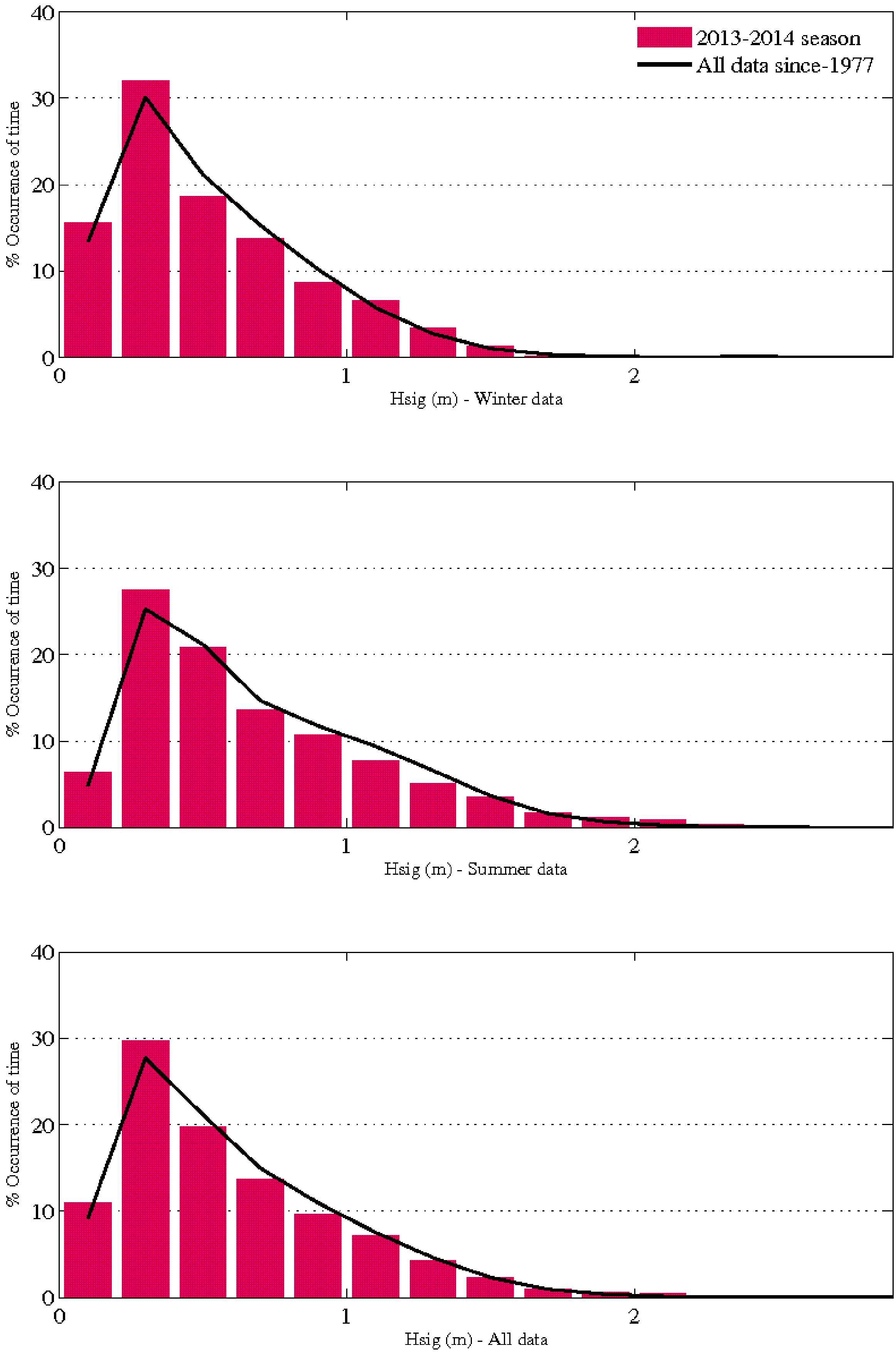


Figure 81 Hay Point – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

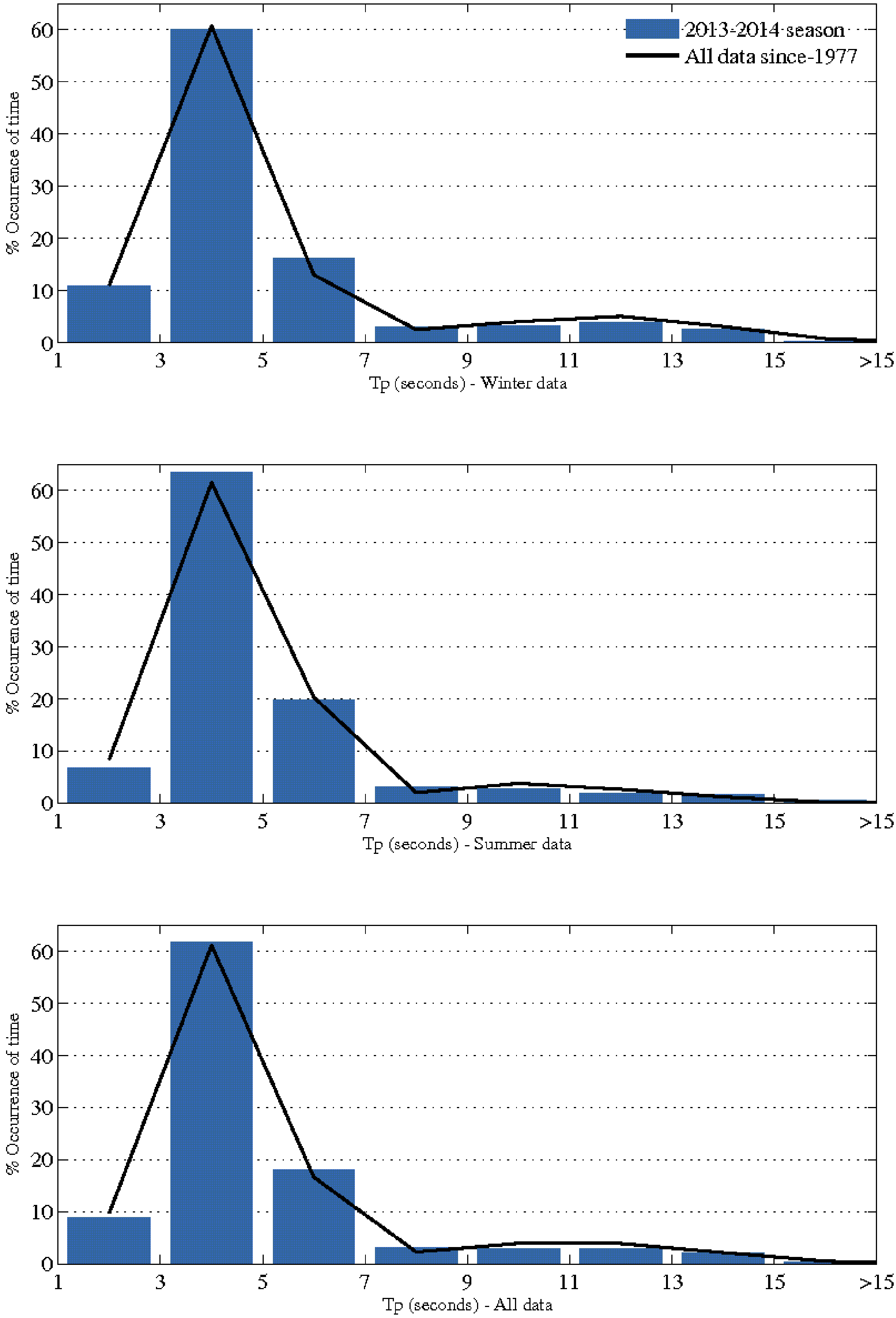


Figure 82 Hay Point – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

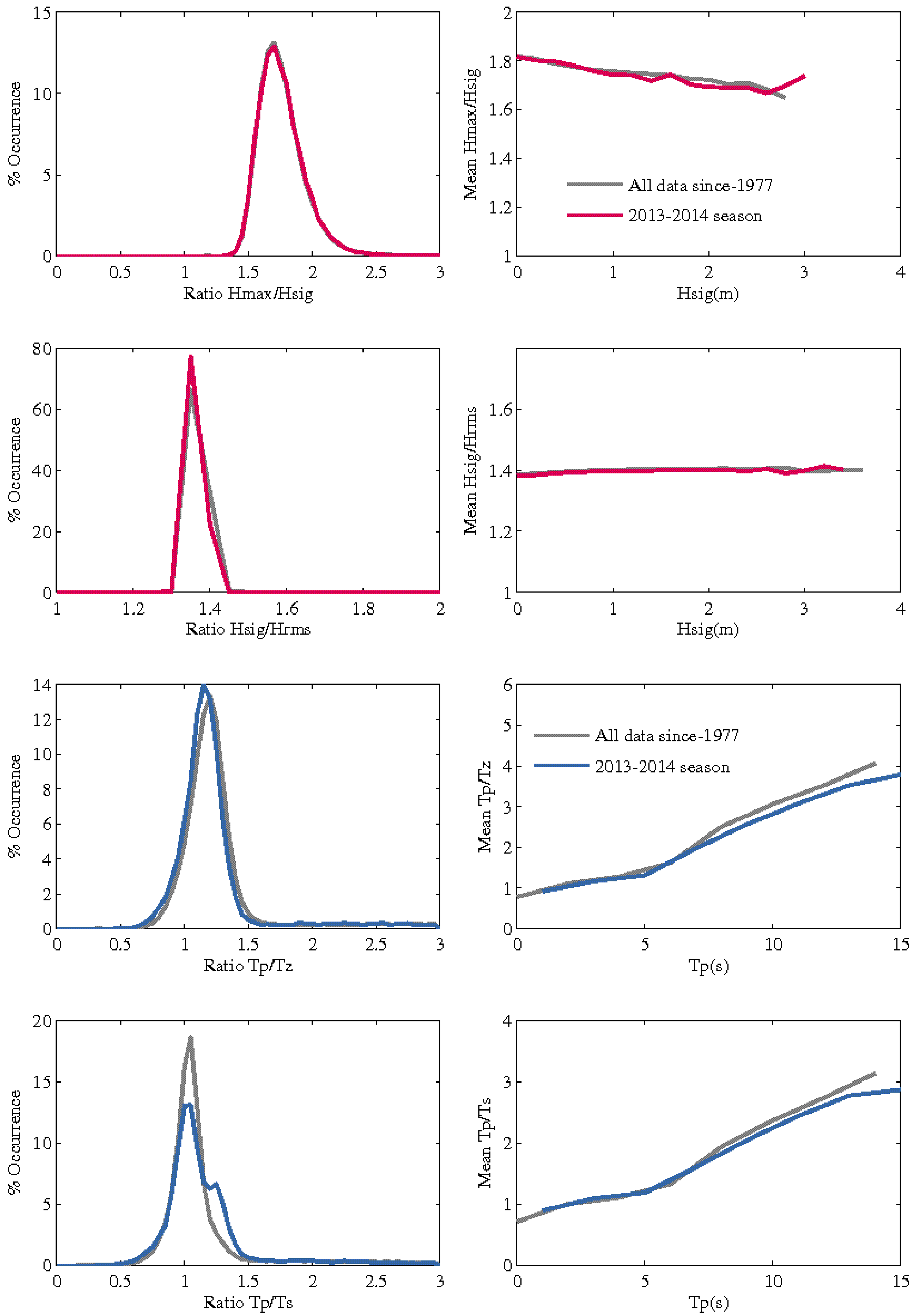
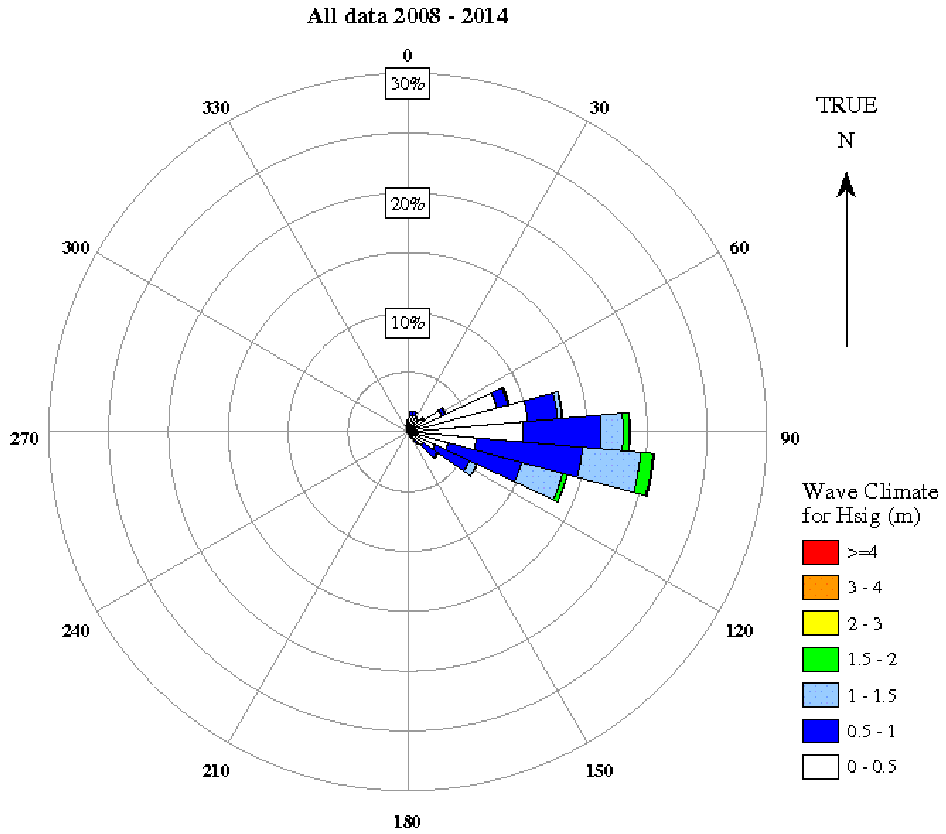


Figure 83 Hay Point – Wave parameter relationships



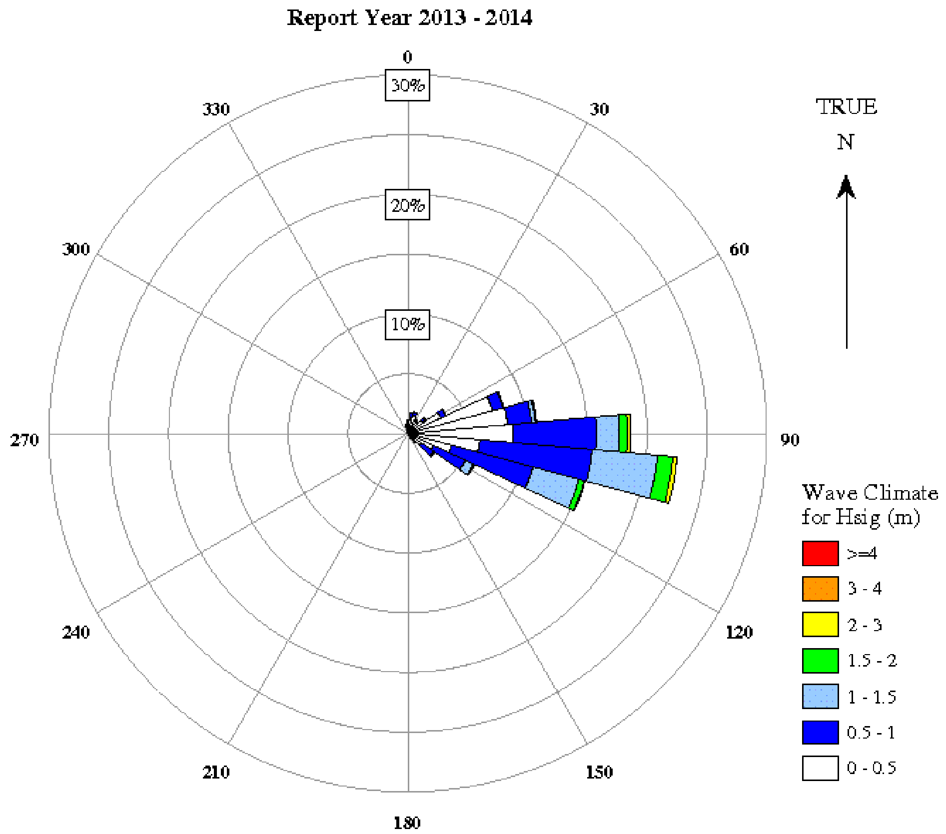


Figure 84 Hay Point – Directional wave rose

7.10 Mackay

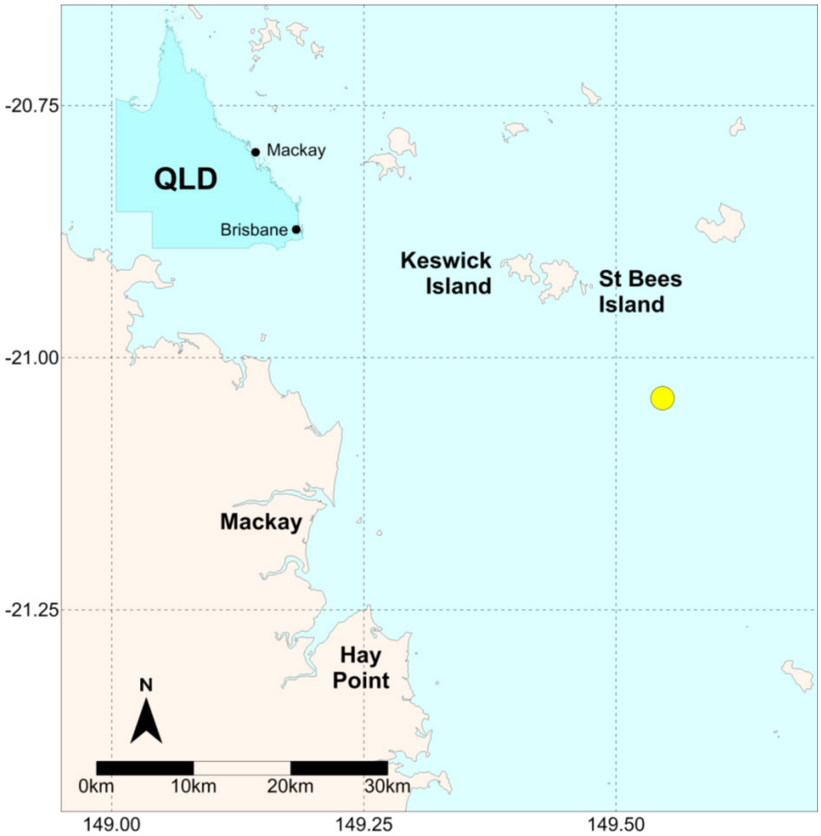


Figure 85 Mackay – Locality plan

Table 40 Hay Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	19/09/1975	na	282685	39.1
2013 -14	1/11/2013	25.27 days	16306	1

Table 41: Mackay – Buoy deployments during the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
21°02.395'S	149°32.759'E	25	23/10/2013	21/04/2014
21°02.426'S	149°32.775'E	27.5	21/04/2014	current

7.10.1 Mackay – seasonal overview

The Mackay wave buoy has been operational for just over 39 years. The data recorded for the period from November 2013 to October 2014 was reasonable, with total gaps of 25.27 days, equivalent to 93.1 percent data return. The buoy was replaced just prior to this reporting period on 23 October 2013 and again on 21 April 2014 (Table 59).

The largest waves during the reporting period occurred on 30 January as a result of TC Dylan reaching landfall as a category 2 tropical cyclone nearby at Bowen. The second highest ranking significant wave height (Hsig) and the highest ranking maximum wave height was recorded from this event (Table 61). Time series of daily wave recordings (Figure 86) show clear increases in wave heights from the influence of significant meteorological events (Table 61) over the duration of the reporting period.

Peak wave direction was predominately from the east-south-east (Figure 87). The Sea surface temperature (SST) up to April 21 was found to be erroneous after calibration of the sensor post buoy retrieval. From April 22 onwards SST ranged from 19.8° C to 26.3° C (Figure 87) where the SST was below the minimum temperature for tropical cyclone development except for a few days during 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 subsequently exceeding +1 sd significantly. November was also on the bounds of exceeding 1 sd.

Percentage exceedance of Hsig (Figure 89) shows a very similar wave climate between the reporting period and the entire record. Summer months experienced higher, less frequent waves than the winter due to the influence of cyclones over summer. Histograms for percentage occurrence of Hsig (Figure 90) and peak weave period (Tp) (Figure 91) also show the same distribution between the recent reporting period and the entire record.

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 42 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 0:00	9.4
3	10/03/1997 0:00	4.8	9/03/1997 11:00	8.5
4	1/03/1979 3:00	4	8/03/2009 17:00	7.7
5	27/12/1990 3:41	3.9	19/01/2004 19:30	7.5

6	5/06/2002 0:00	3.8	4/03/2002 15:00	7.3
7	19/01/2004 19:30	3.6	17/02/2008 19:30	7.1
8	17/02/2008 19:30	3.6	5/06/2002 1:00	6.9
9	12/01/1979 3:00	3.6	26/12/2007 1:30	6.9
10	18/03/2012 23:30	3.5	9/05/1996 19:30	6.8

Table 43 Mackay – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
30/01/2014 19:30	4.9 (5.0)	8.2 (10.0)	10.2	Tropical Cyclone Dylan [990 hPa] formed northeast of Townsville on January 30 and made landfall as a category 2 on the morning of 31 January near Bowen.
10/03/2014 7:00	3.0 (3.2)	5.8 (6.7)	8.2	A low over the Coral Sea moved southwest towards Mackay intensifying to become Tropical Cyclone Hadi [992 hPa] on the 10 March.
13/04/2014 23:30	3.0 (3.2)	4.6 (6.0)	7.2	Tropical Cyclone Ita [995 hPa] passed from north to south as a category 1 cyclone.
10/06/2014 21:00	3.0 (3.2)	5.2 (5.9)	7.7	A trough extending along the east coast and a low [1006] were present in the coral sea.
11/04/2013 21:00	2.6 (3.1)	4.9 (5.8)	7.9	Deepening surface trough in the Western Coral Sea [1004 hPa]

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.

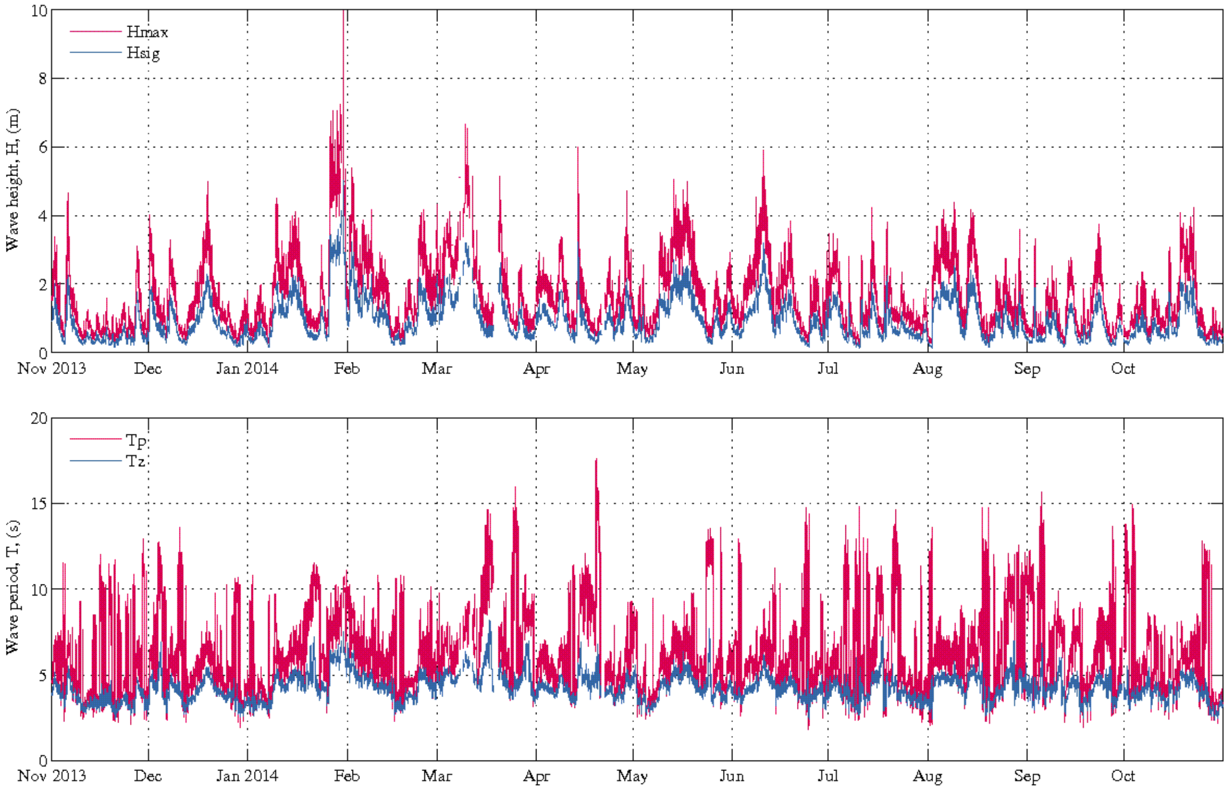


Figure 86 Mackay – Daily wave recordings

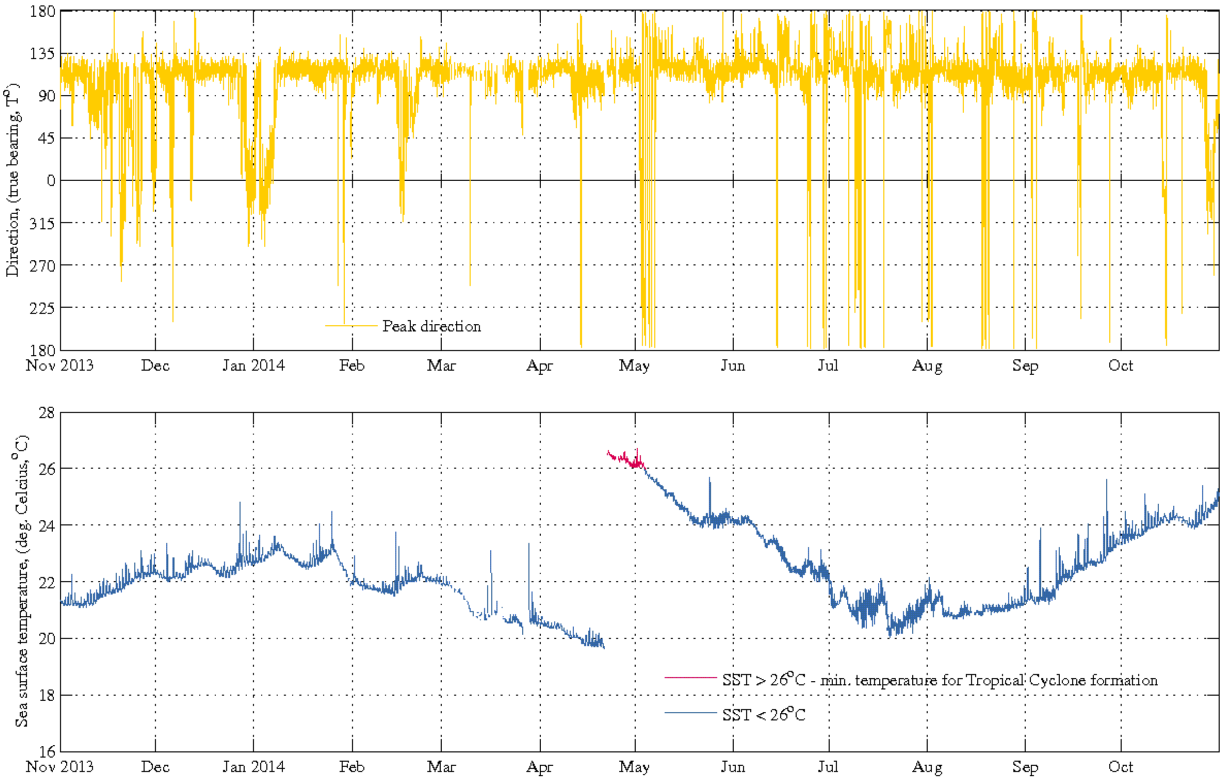


Figure 87 Mackay – Sea surface temperature and peak wave directions

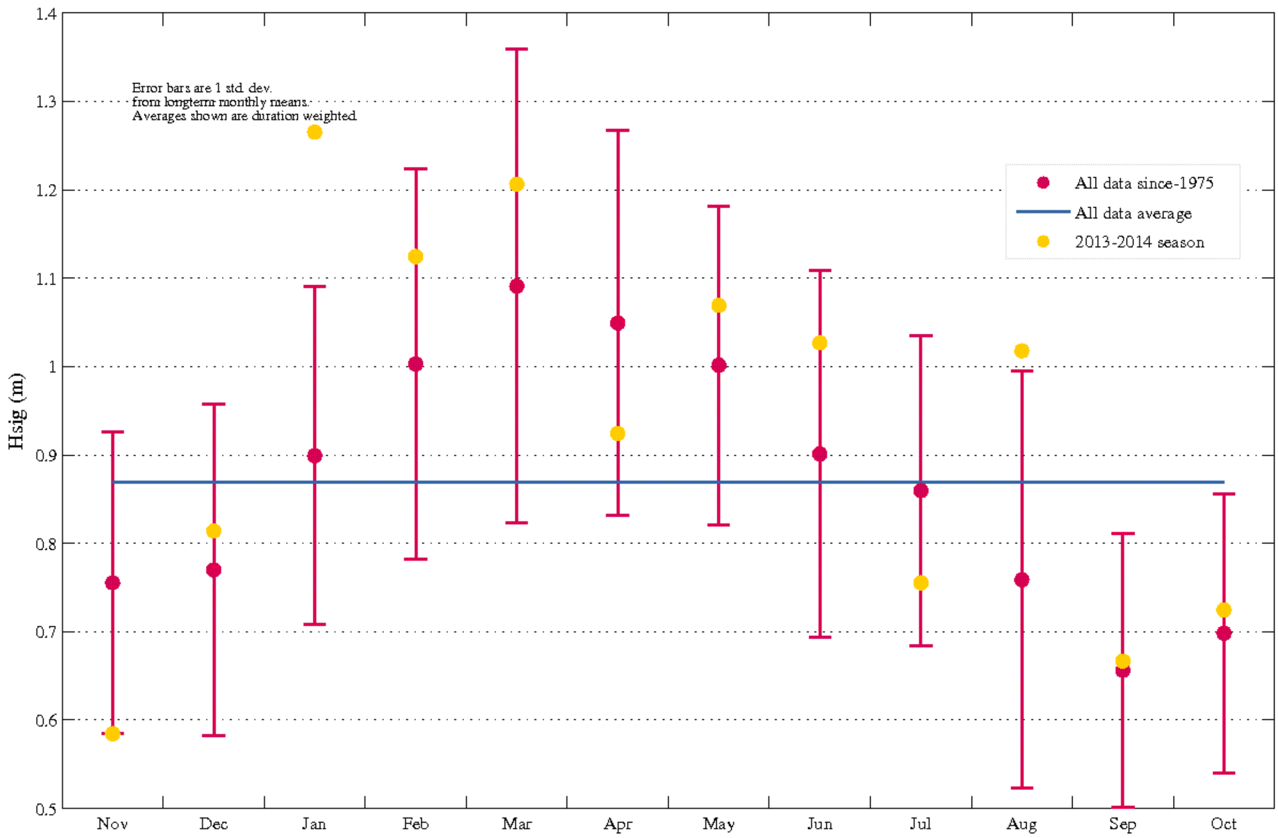


Figure 88 Mackay – Monthly average wave height (Hsig) for seasonal year and for all data

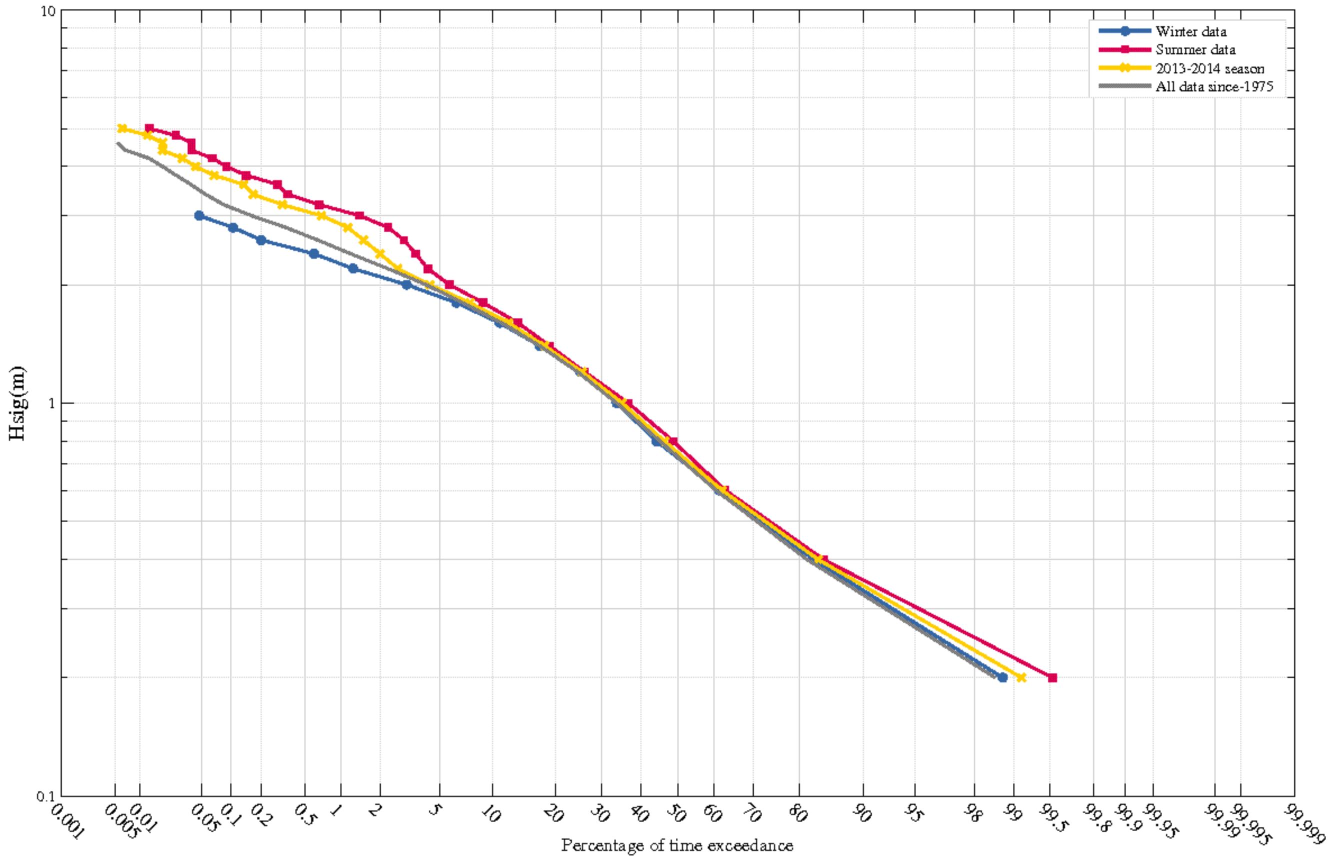


Figure 89 Mackay – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

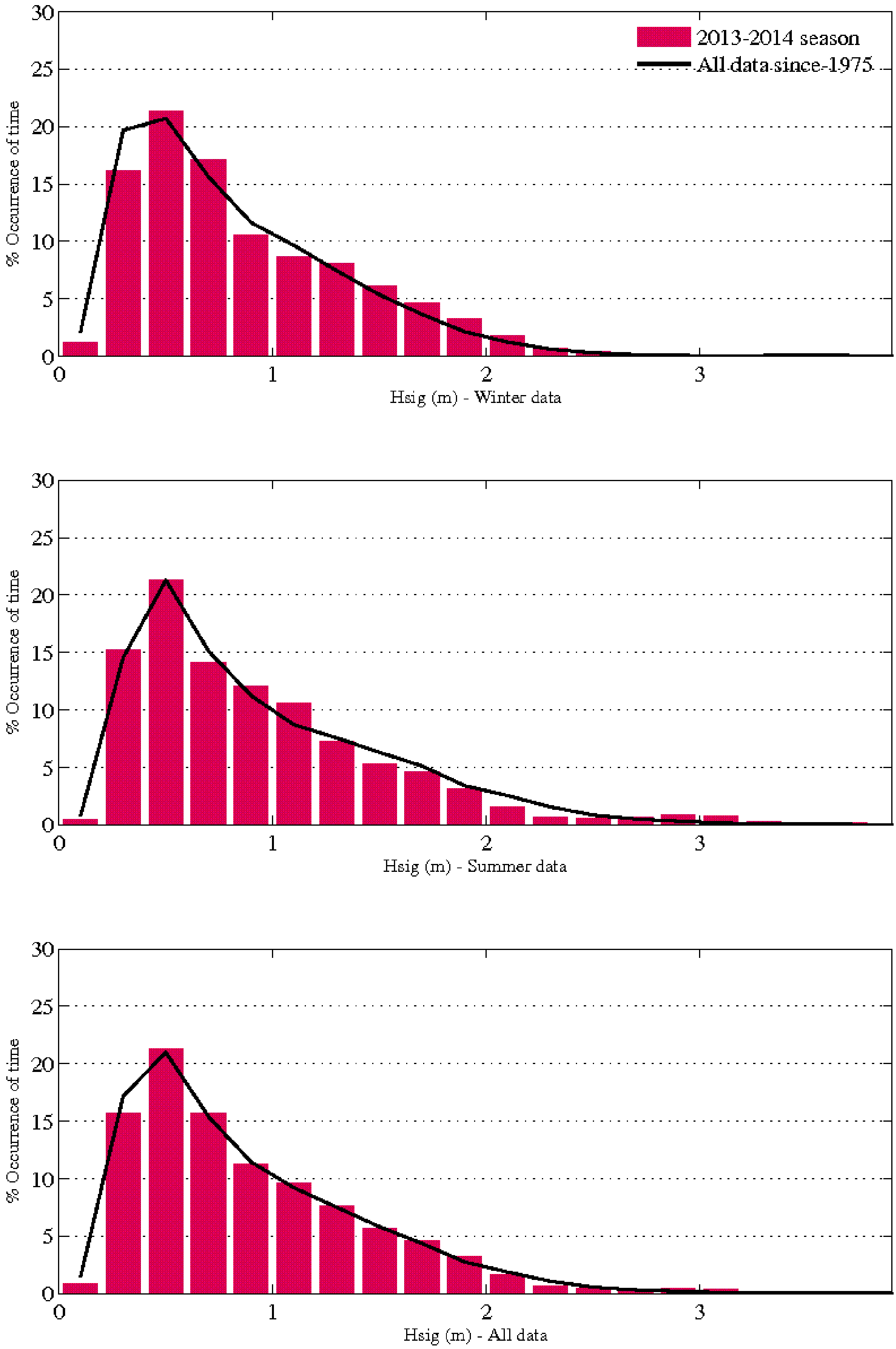


Figure 90 Mackay – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

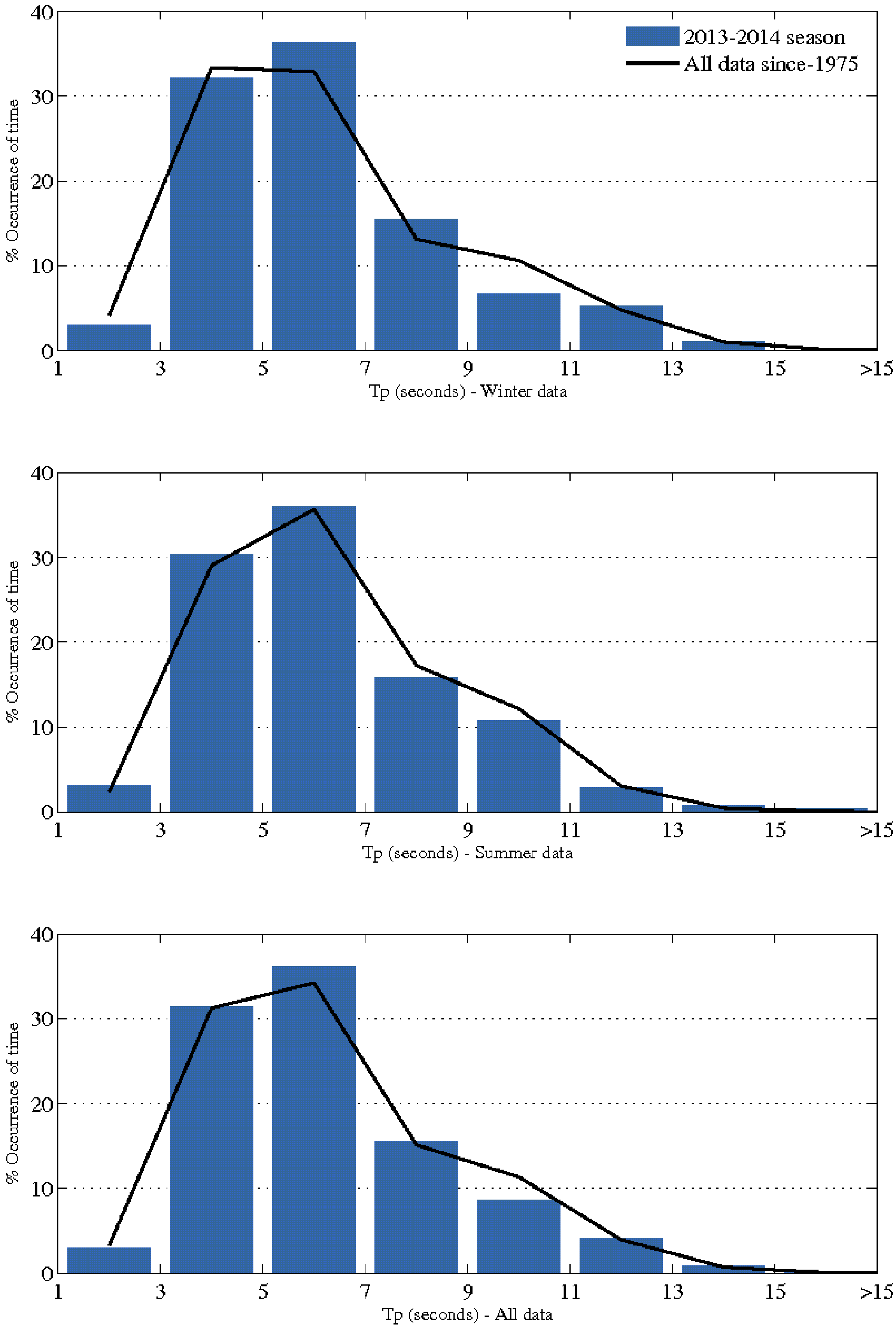


Figure 91 Mackay – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

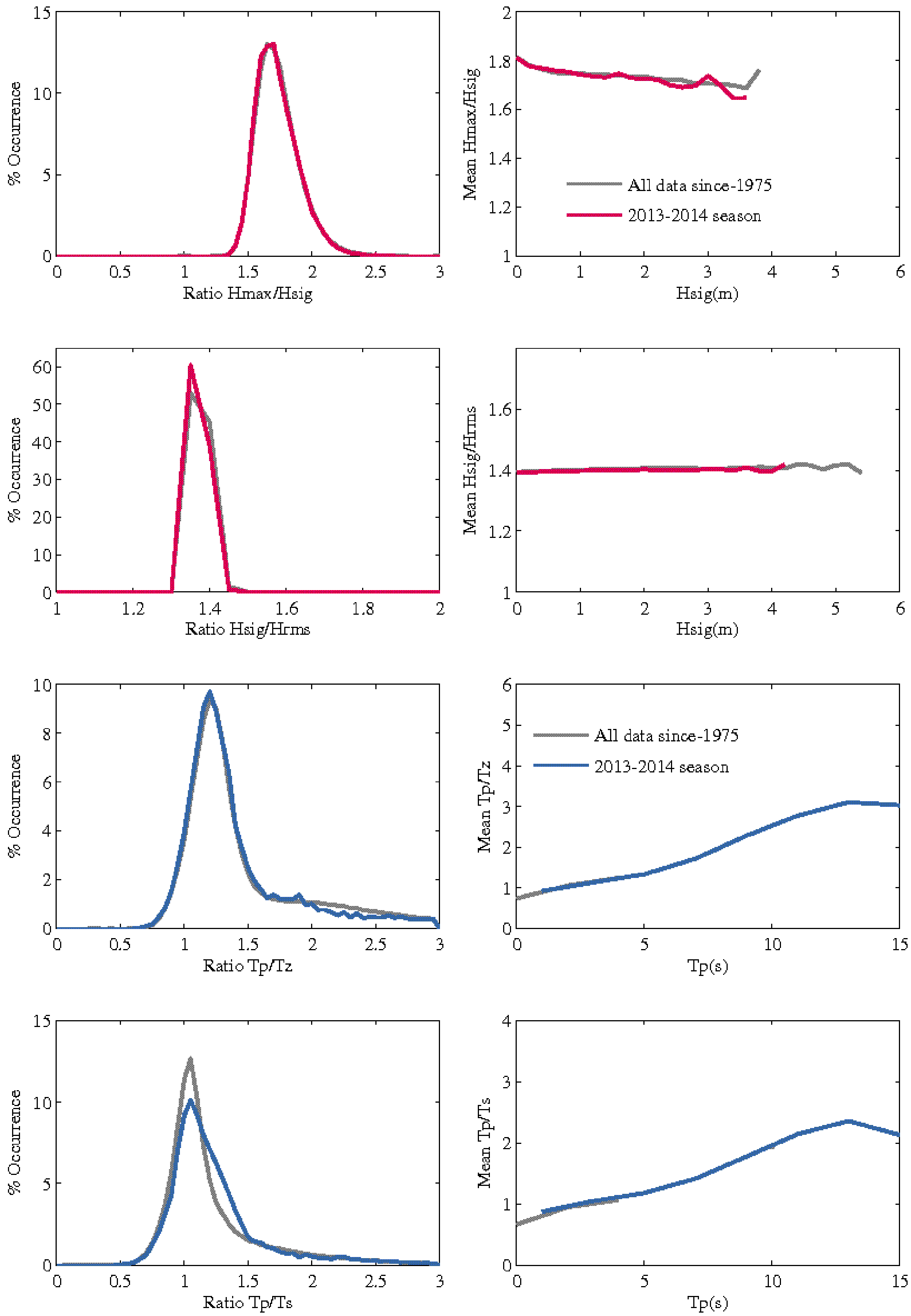
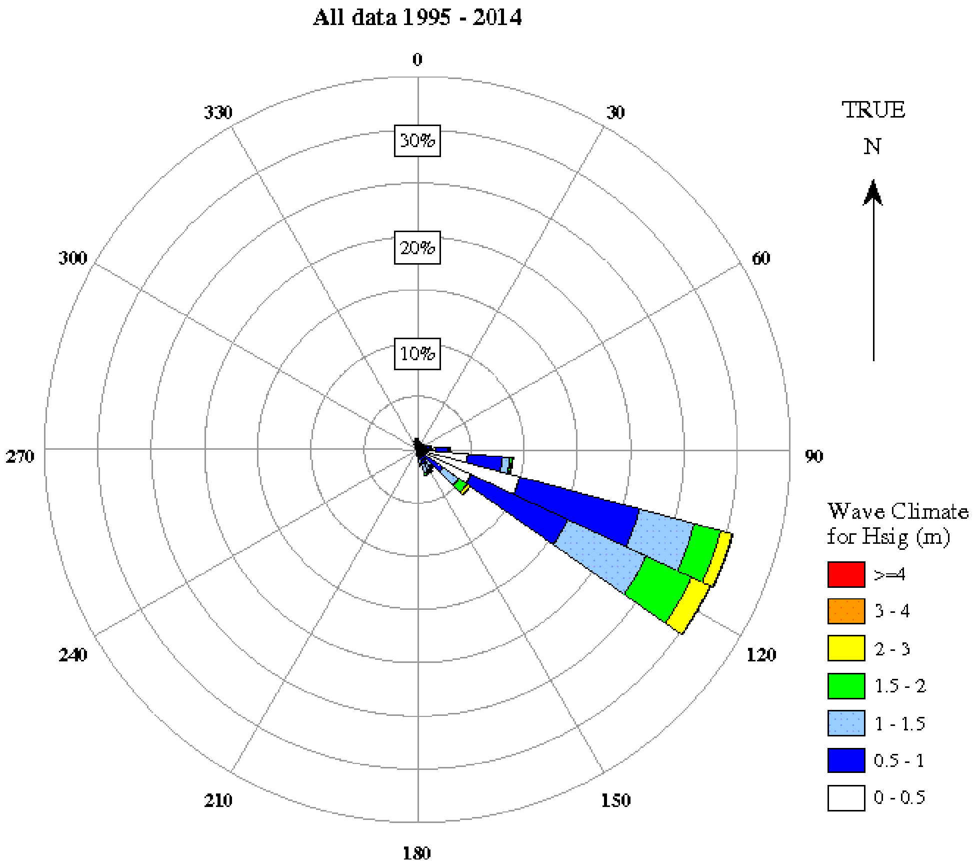


Figure 92 Mackay – Wave parameter relationships



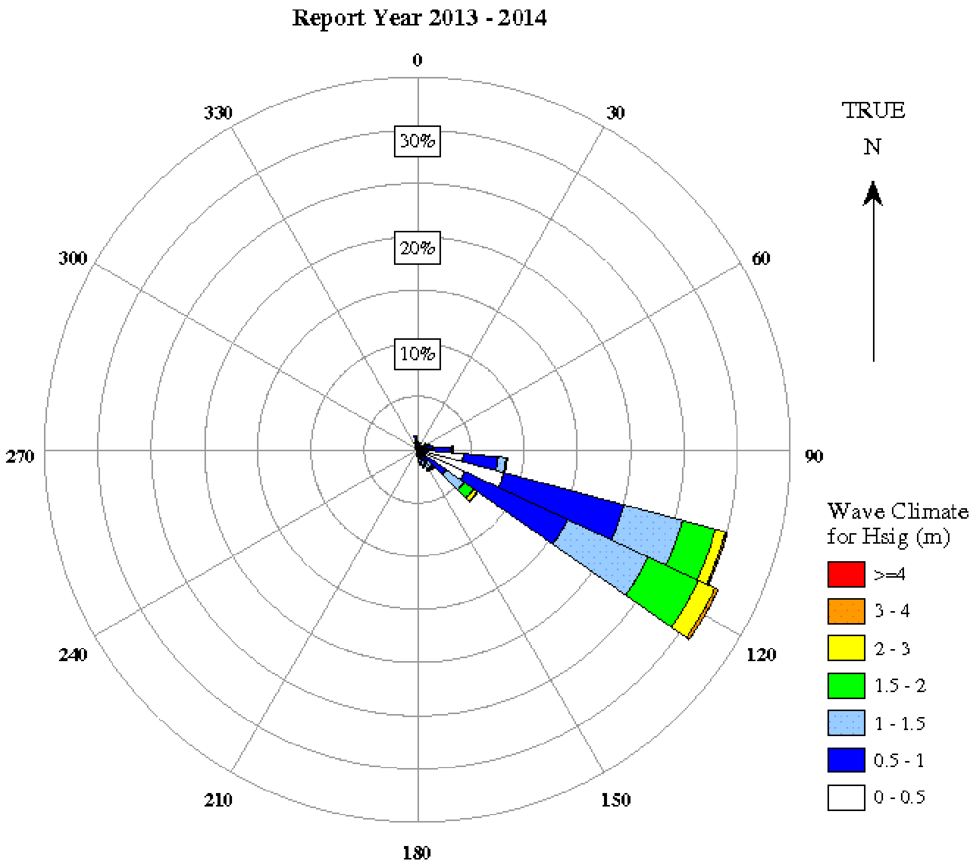


Figure 93 Mackay – Directional wave rose

7.11 Abbot Point

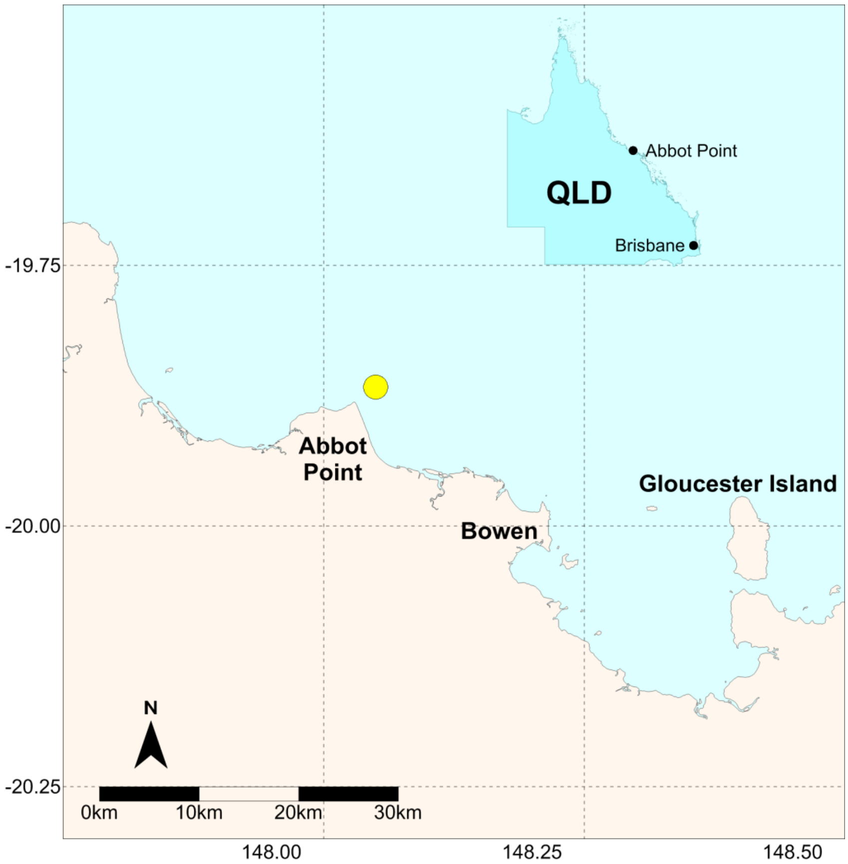


Figure 94 Abbot Point – Locality plan

Table 44 Abbot Point – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	17/01/2012	0.06 years	47756	2.8
2013 -14	1/11/2013	17.65 days	16672	1

Table 45 Abbot Point – Buoy deployment for the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
19°52.085'S	148°05.968'E	16	31/10/2012	05/02/2014
19°51.975'S	148°05.845'E	14	05/02/2014	current

7.11.1 Abbot Point – seasonal overview

The Abbot Point wave buoy has only been operational for just under 3 years. The Abbot Point buoy has only been operational for a short period of time. Comparisons have been made in this report between previous recordings and recordings made in this reporting period for the first time.

The data recorded for the period November 2013 to October 2014 was reasonably good with the buoy experiencing an outage during February due to transmission failure. There was a total gap of 17.65 days, equivalent to 95.2% data return. The buoy was replaced once during the reporting period on 5 February.

The largest waves recorded by the Abbot Point wave rider buoy during the reporting period occurred in April as TC Ita tracked from north to south along the east coast of Queensland. This generated a significant wave height (Hsig) of 3.8 m and a maximum wave height (Hmax) of 6.5 m on 13 April. Spikes in peak wave period (Tp) of 20 seconds seen in the daily wave recordings (Figure 95) are likely to be erroneous.

Peak wave direction (Figure 96) was predominately from east-north-east. Sea Surface Temperature (SST) values ranged from 19.8°C to 30.5°C (Figure 96) were the SST was high enough for tropical cyclone development for summer months with the exception of periods during March and April.

Percentage exceedance of Hsig (Figure 98) and the histogram of percentage occurrence of Hsig (Figure 99) show summer to have greater wave heights than winter. The most common Tp was between 3 and 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 46 Abbot Point – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	13/04/2014 14:30	3.8	13/04/2014 14:30	6.5
2	24/01/2013 16:00	3.0	24/01/2013 19:00	5.5
3	21/03/2012 03:00	1.9	12/04/2013 00:00	3.6
4	12/04/2013 00:00	1.8	20/03/2012 23:00	3.4
5	02/02/2012 07:00	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	09/03/2014 15:00	1.6	12/04/2012 15:00	3.3

8	11/07/2012 03:00	1.5	01/12/2013 22:30	3.2
9	6/09/2013 11:00	1.5	2/02/2012 07:00	3.2
10	28/01/2014 16:30	1.5	19/12/2013 13:30	3.0

Table 47 Abbot Point – Significant meteorological events with threshold Hsig of 2.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
13/04/2014 14:30	3.2 (3.8)	5.2 (6.5)	7.9	Tropical Cyclone Ita [995 hPa] passed from north to south as a category 1 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 95 Abbot Point – Daily wave recordings

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

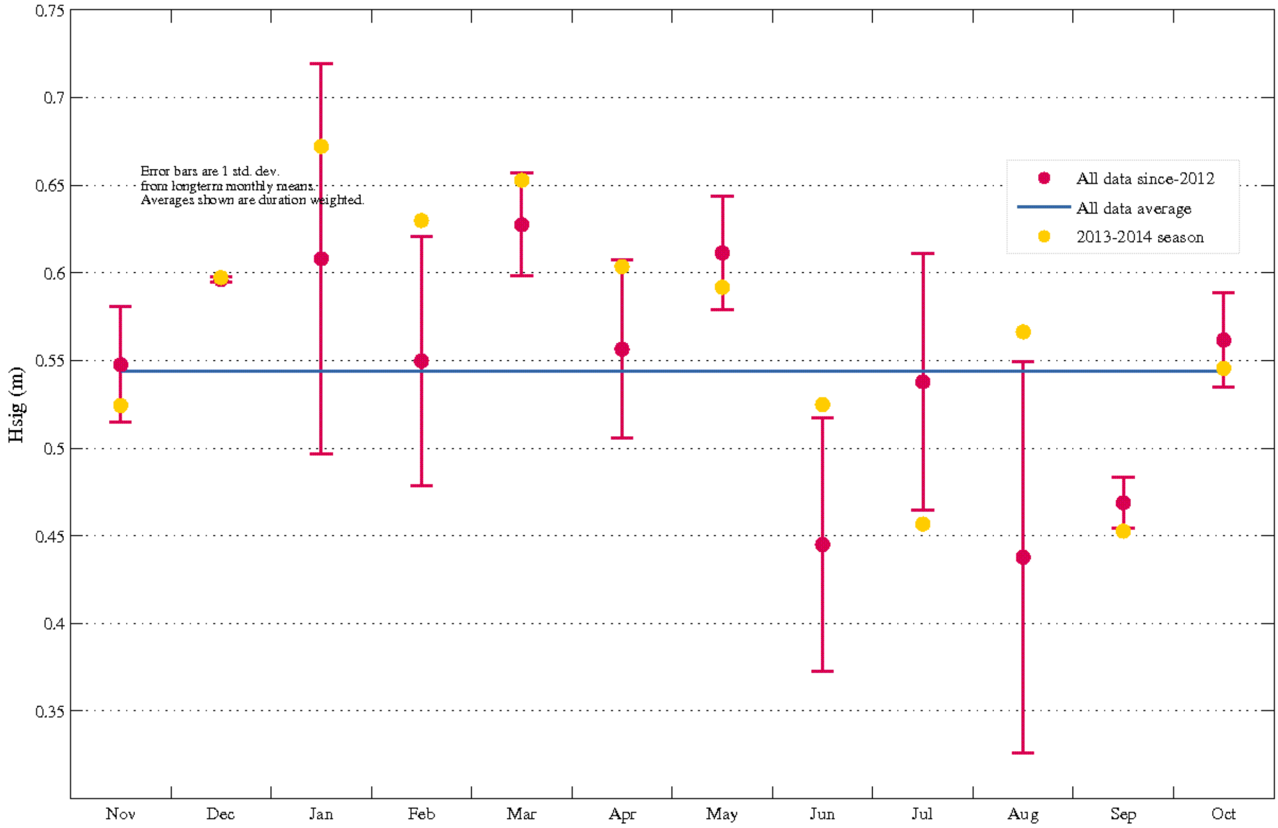


Figure 97 Abbot Point – Monthly average wave height (Hsig) for seasonal year and for all data

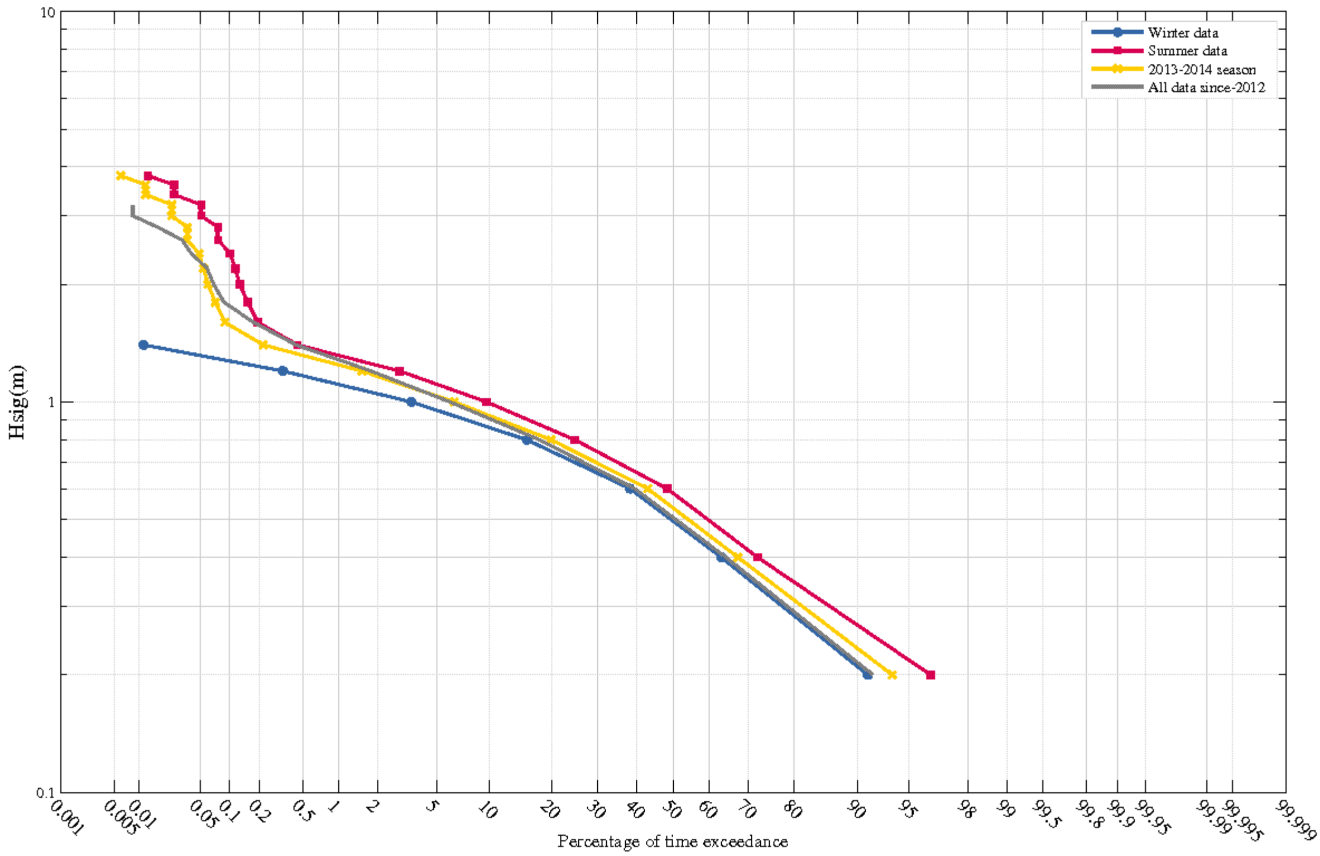


Figure 98 Abbot Point – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

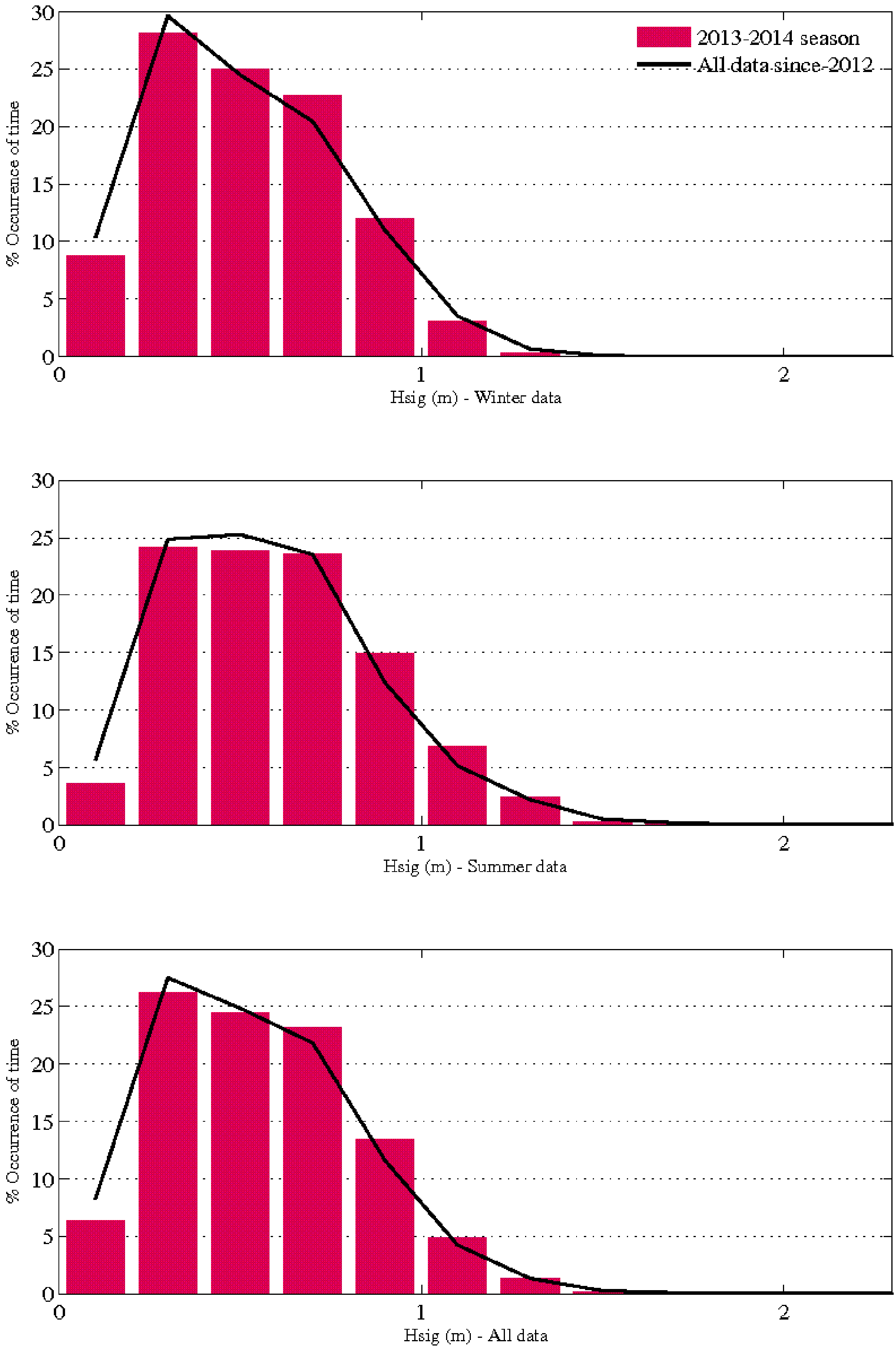


Figure 99 Abbot Point – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

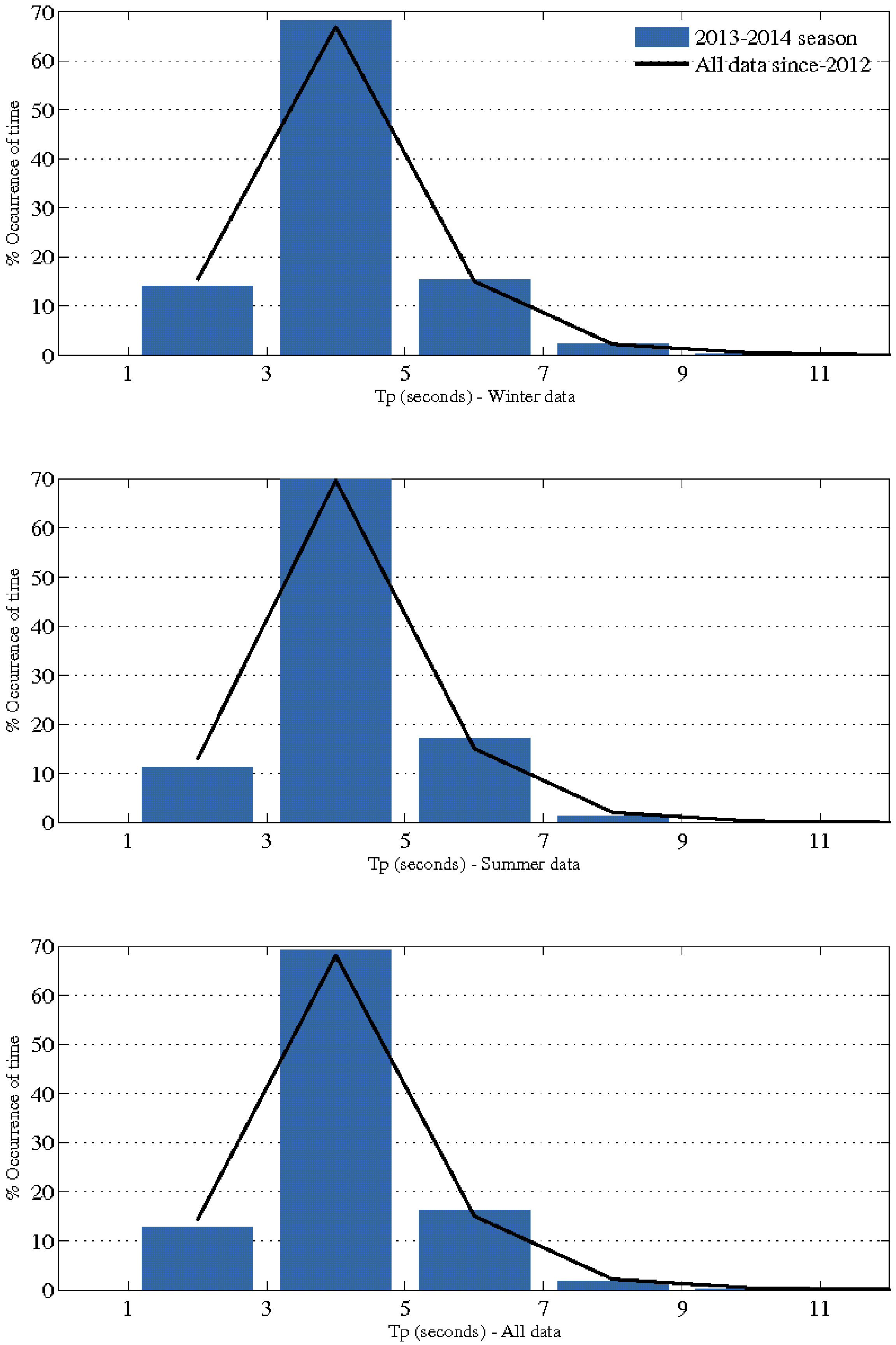


Figure 100 Abbot Point – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

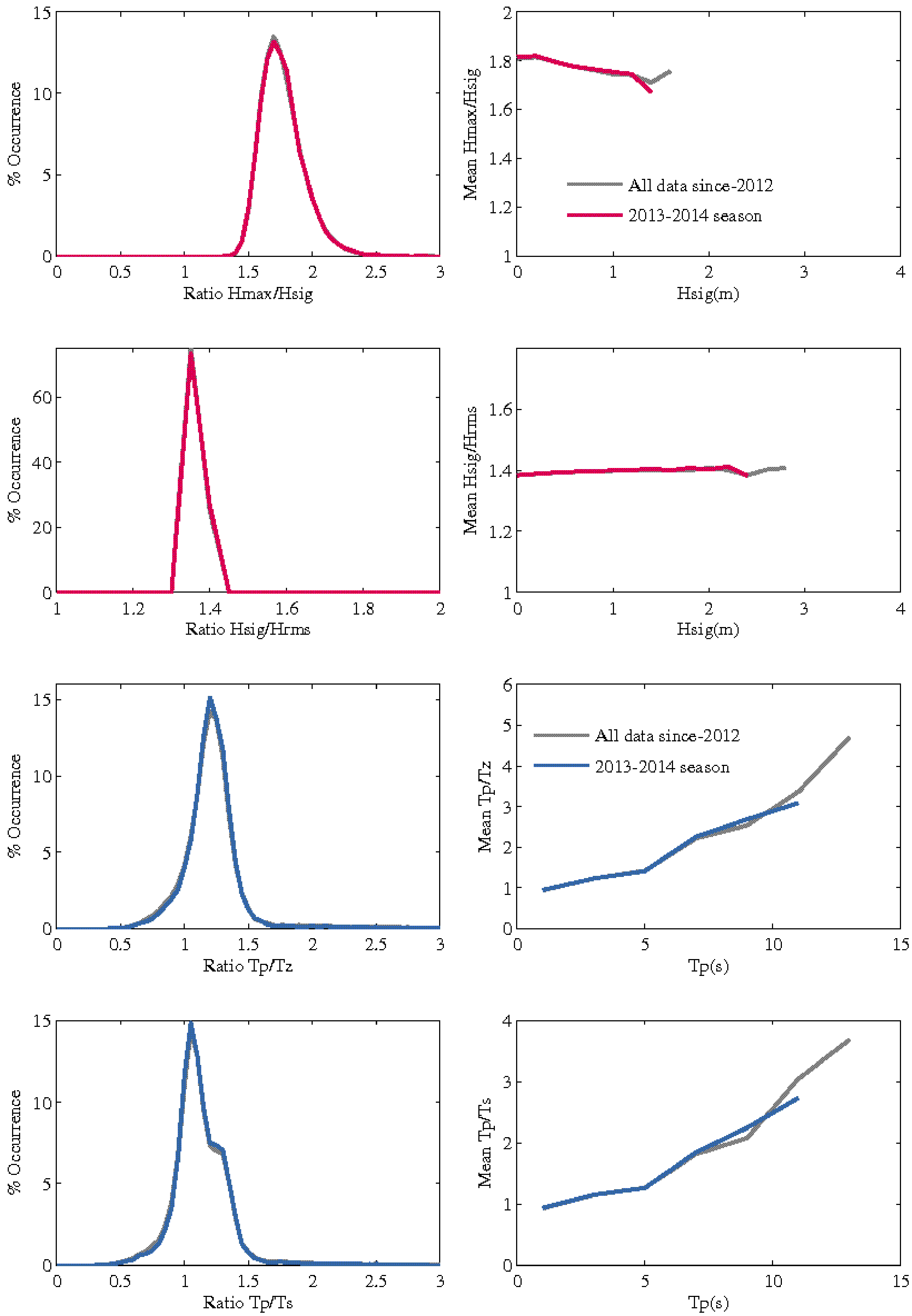


Figure 101 Abbot Point – Wave parameter relationships

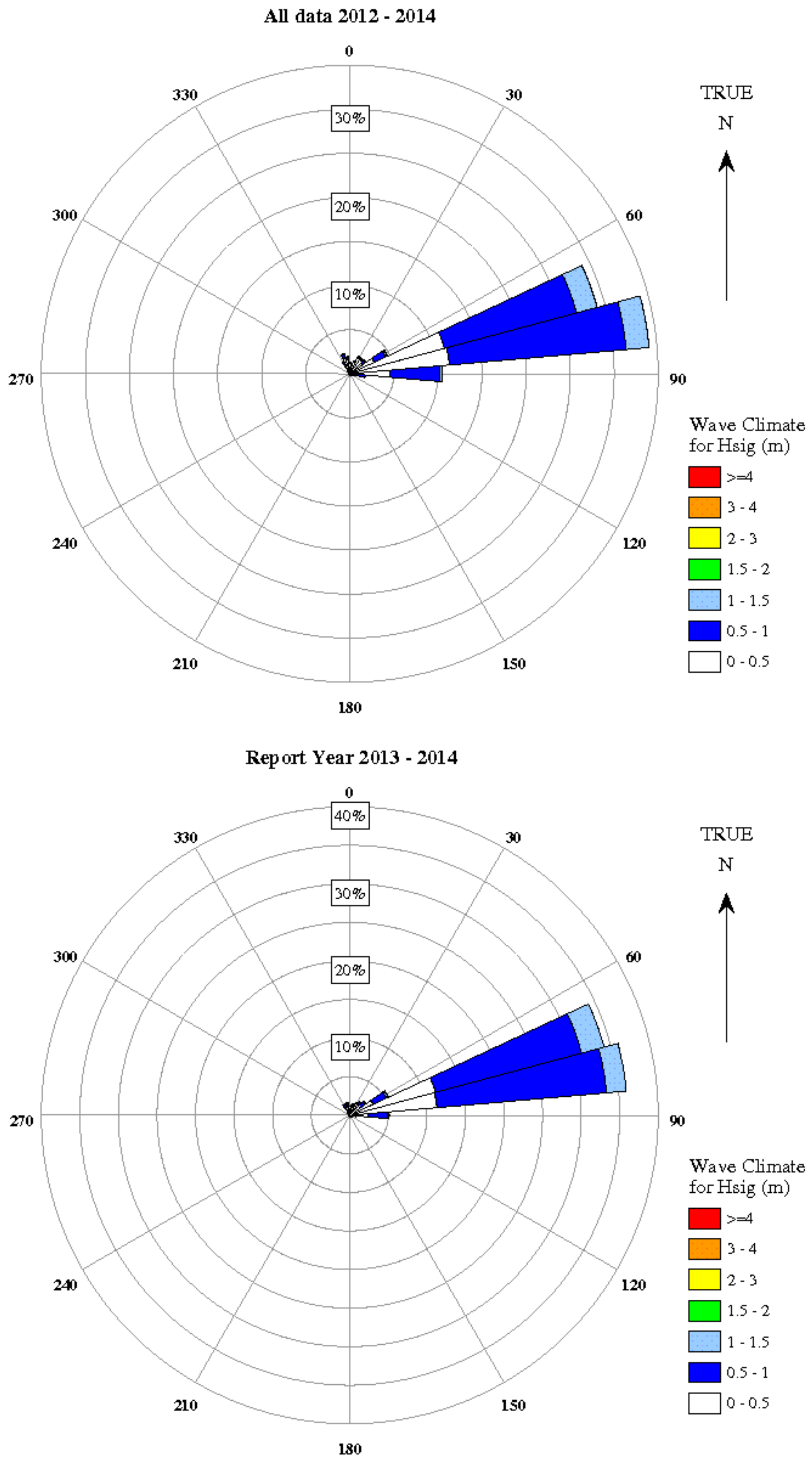


Figure 102 Abbot Point – Directional wave rose

7.12 Townsville

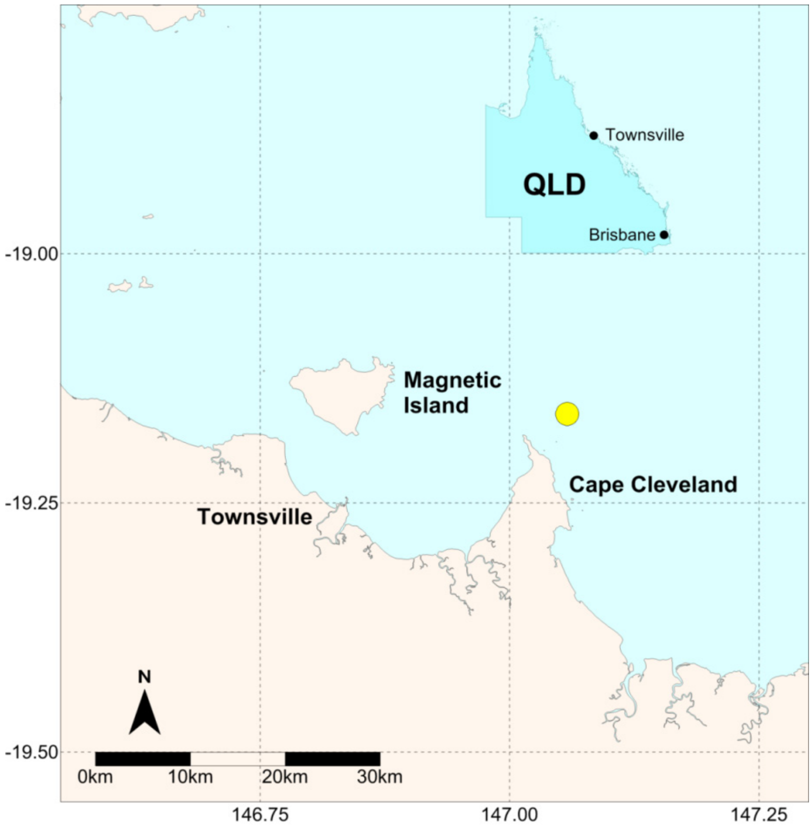


Figure 103 Townsville – Locality plan

Table 48 Townsville – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	20/11/1975	na	297562	39.9
2013 -14	1/11/2013	59.67 days	14655	1

Table 49 Townsville – Buoy deployments during the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date	Reason for change
19°09.648'S	147°03.521'E	16	29/01/2013	17/03/2014	Ship strike
19°19.608'S	147°03.551'E	15	17/03/2014	23/07/2014	Lost comms
19°09.576'S	147°03.515'E	16	23/07/2014	Current	-

7.12.1Townsville – seasonal overview

The Townsville wave buoy has been operational for nearly 39 years. The data recorded for the period November 2013 to October 2014 experienced extended outages due to the buoy being struck by a ship in February and because of transmission failure during July. There was a total gap of 59.67 days, equivalent to 83.7 percent data return. The buoy was replaced twice during the reporting period because of the previously mentioned issues (Table 85).

The largest waves during the reporting period occurred in April as TC Ita tracked south along the Queensland coast. The third highest ranking significant wave height (Hsig) and maximum wave height (Hmax) recorded by the buoy were set from this event on 13 April (Table 86). Time series of daily wave recordings (Figure 104) show clear increases in wave heights from the influence of significant meteorological events (Table 87) over the duration of the reporting period.

Peak wave direction (Figure 105) was predominately from the east with an occasional swing to the north-east. Sea surface temperature (SST) values ranged from 21° C to 30.5° C (Figure 105) where the SST was high enough for tropical cyclone development throughout summer months.

Monthly average Hsig (Figure 106) was within one standard deviation (sd) of the entire data record monthly means for all months except during February which experienced wave heights much greater than +1 sd. It is noted though that the monsoon trough experienced in the region in early February, which increased wave heights, was followed shortly after by buoy failure due to being struck by a ship, so the large deviance in February is likely to be misleading.

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. 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.

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

Table 50 Townsville – Highest waves

Rank	Date (Hs)	Hs (m)	Date (Hmax)	Hmax (m)
1	3/02/2011 1:30	5.5	3/02/2011 1:00	10.1
2	13/01/2009 8:00	3.7	13/01/2009 7:30	6.6
3	13/04/2014 9:00	3.6	13/04/2014 9:30	6.4
4	24/03/1997 2:00	3.6	24/03/1997 3:00	6
5	30/01/2010 22:30	3	24/01/2013 7:30	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 8:00	5.3
8	20/03/2006 8:00	2.9	30/01/2010 20:30	5.2
9	3/03/1979 3:00	2.8	11/02/1999 18:30	5.1
10	24/01/2013 6:30	2.7	1/02/1986 20:49	4.9
10	11/02/2008 19:00	2.7	22/10/1996 21:30	4.9

Table 51 Townsville – Significant meteorological events with threshold Hsig of 1.8m

Date	Hs (m)	Hmax (m)	Tp (s)	Event
29/01/2014 21:30	1.8 (1.9)	3.2 (4.2)	7.6	Tropical depression present in the Coral Sea which would eventually intensify to form TC Dylan [990 hPa].
3/02/2014 5:00	1.8 (2.0)	3.0 (3.7)	7.4	Monsoon trough across north Queensland and a low [997 hPa] present in the Coral Sea.
13/04/2014 9:00	3.1 (3.6)	5.2 (6.4)	7.7	Tropical Cyclone Ita [995 hPa] passed from north to south as a category 1 cyclone.
8/08/2014 19:30	1.8 (1.9)	3.2 (3.8)	6.4	
19/10/2014	1.9 (2.0)	3.2 (3.9)	6.7	

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.

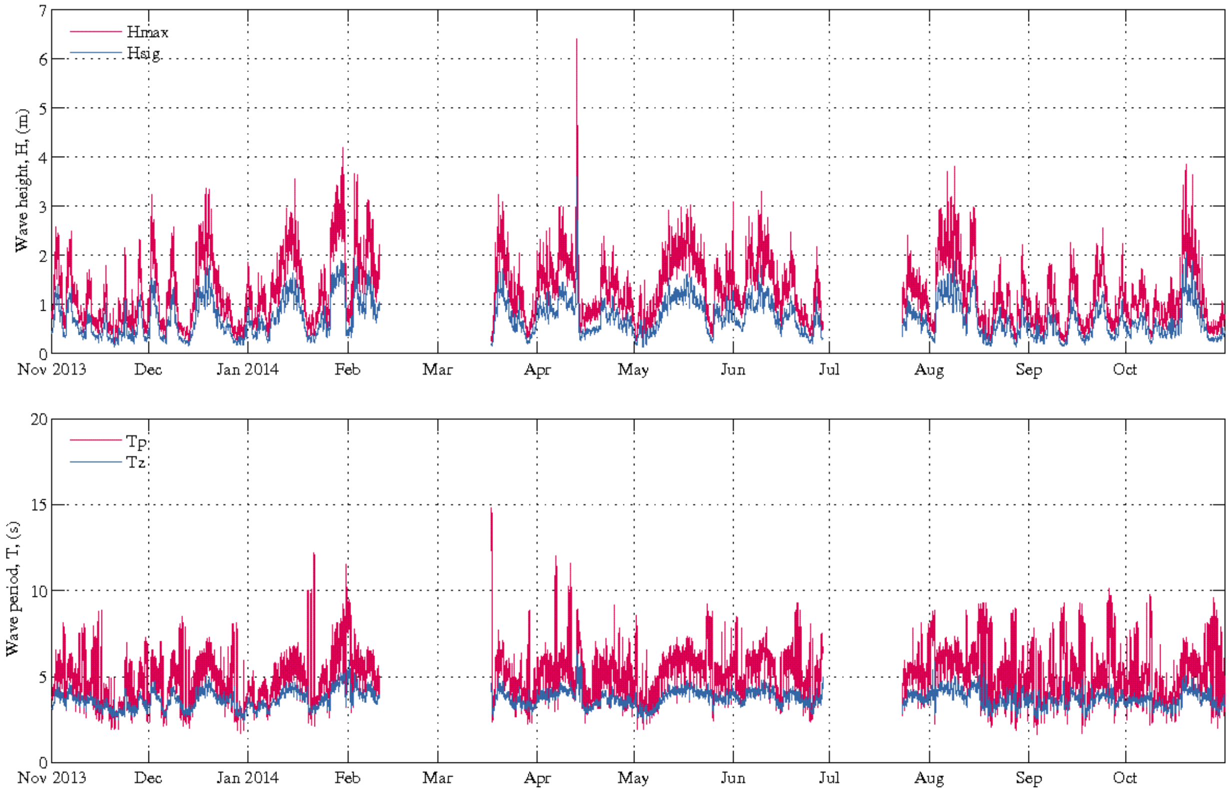


Figure 104 Townsville – Daily wave recordings

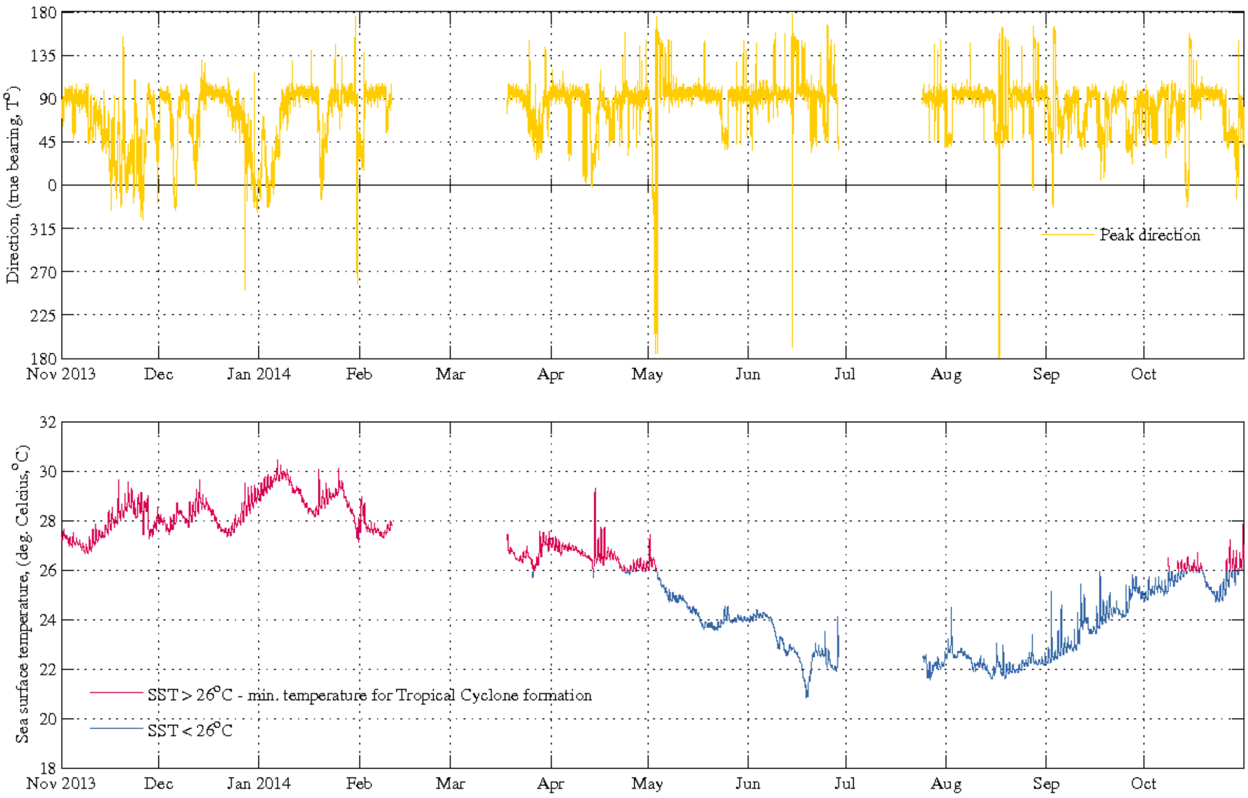


Figure 105 Townsville – Sea surface temperature and peak wave directions

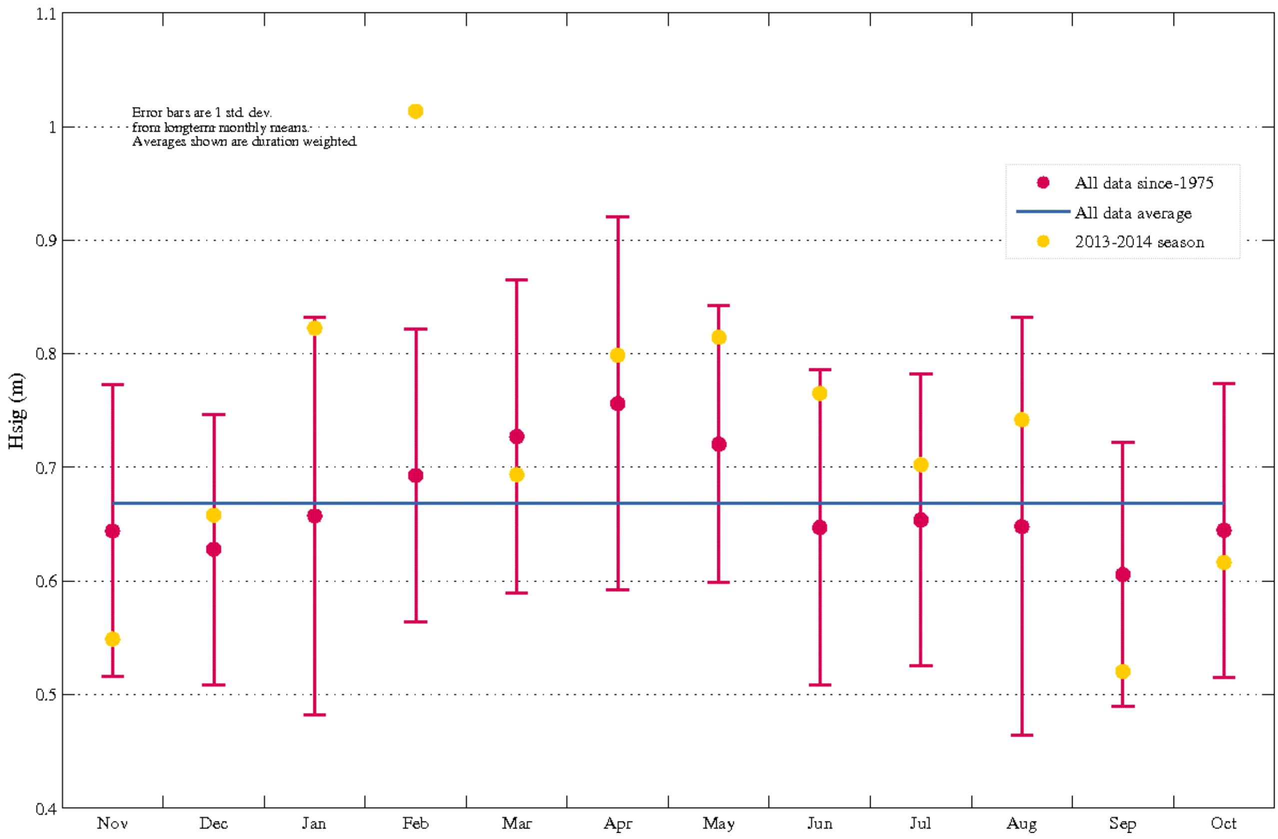


Figure 106 Townsville - Monthly average wave height (Hsig) for seasonal year and for all data

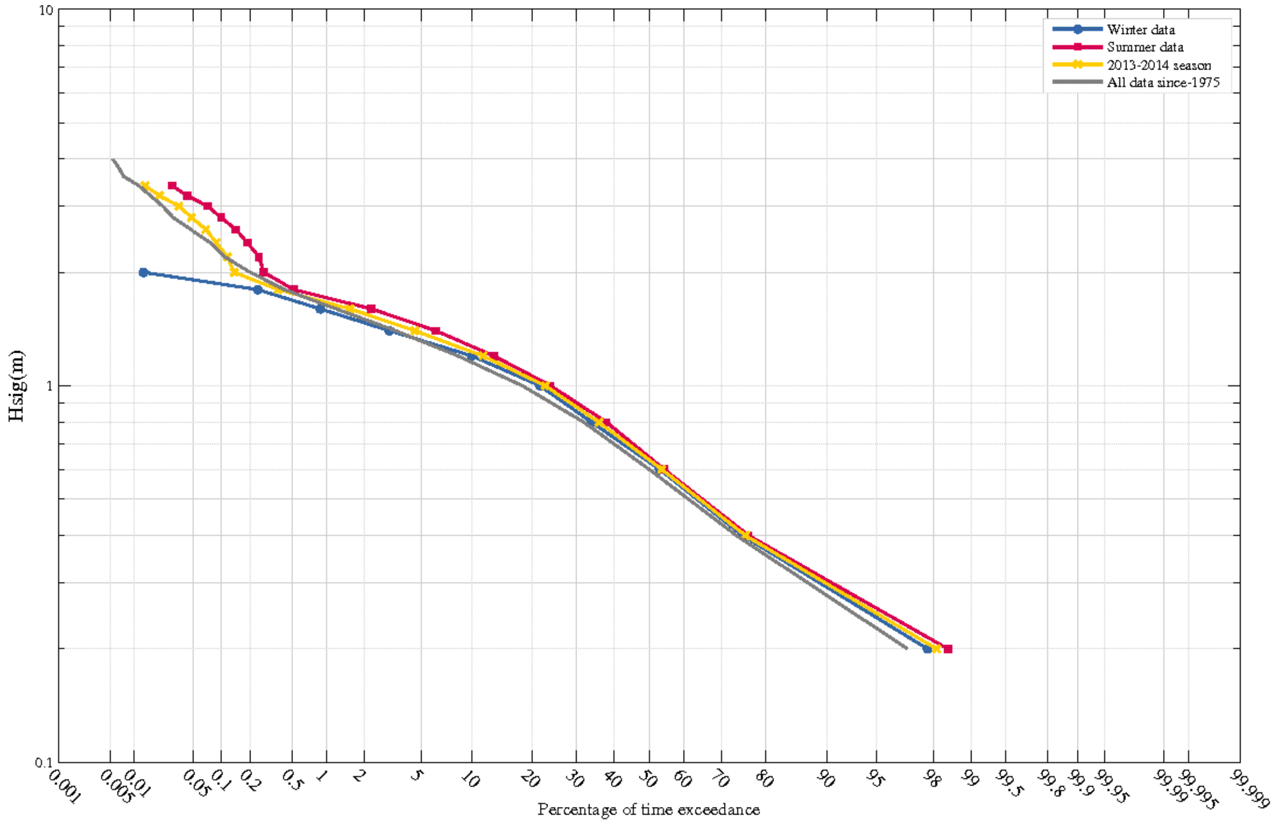


Figure 107 Townsville – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

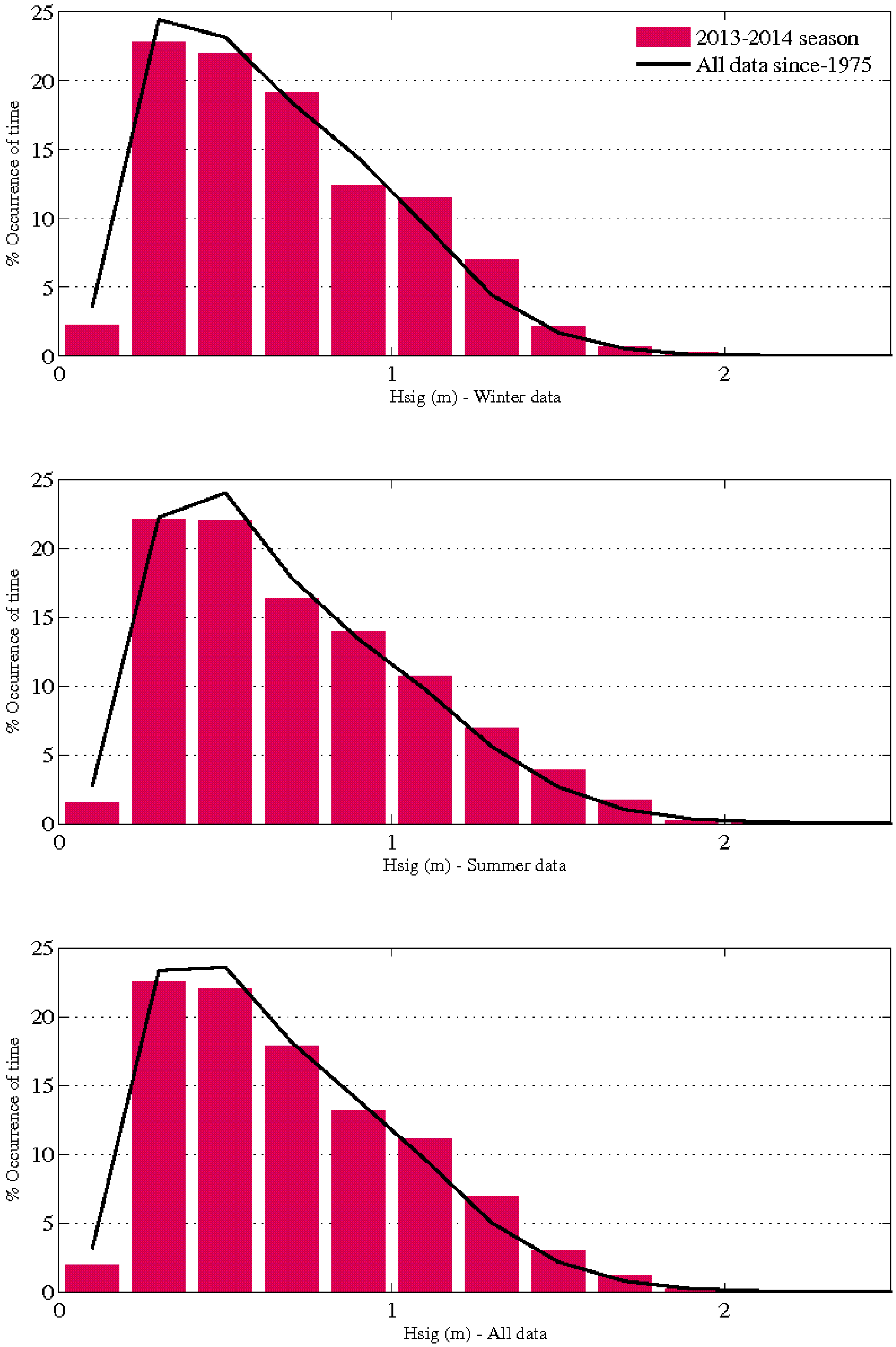


Figure 108 Townsville – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

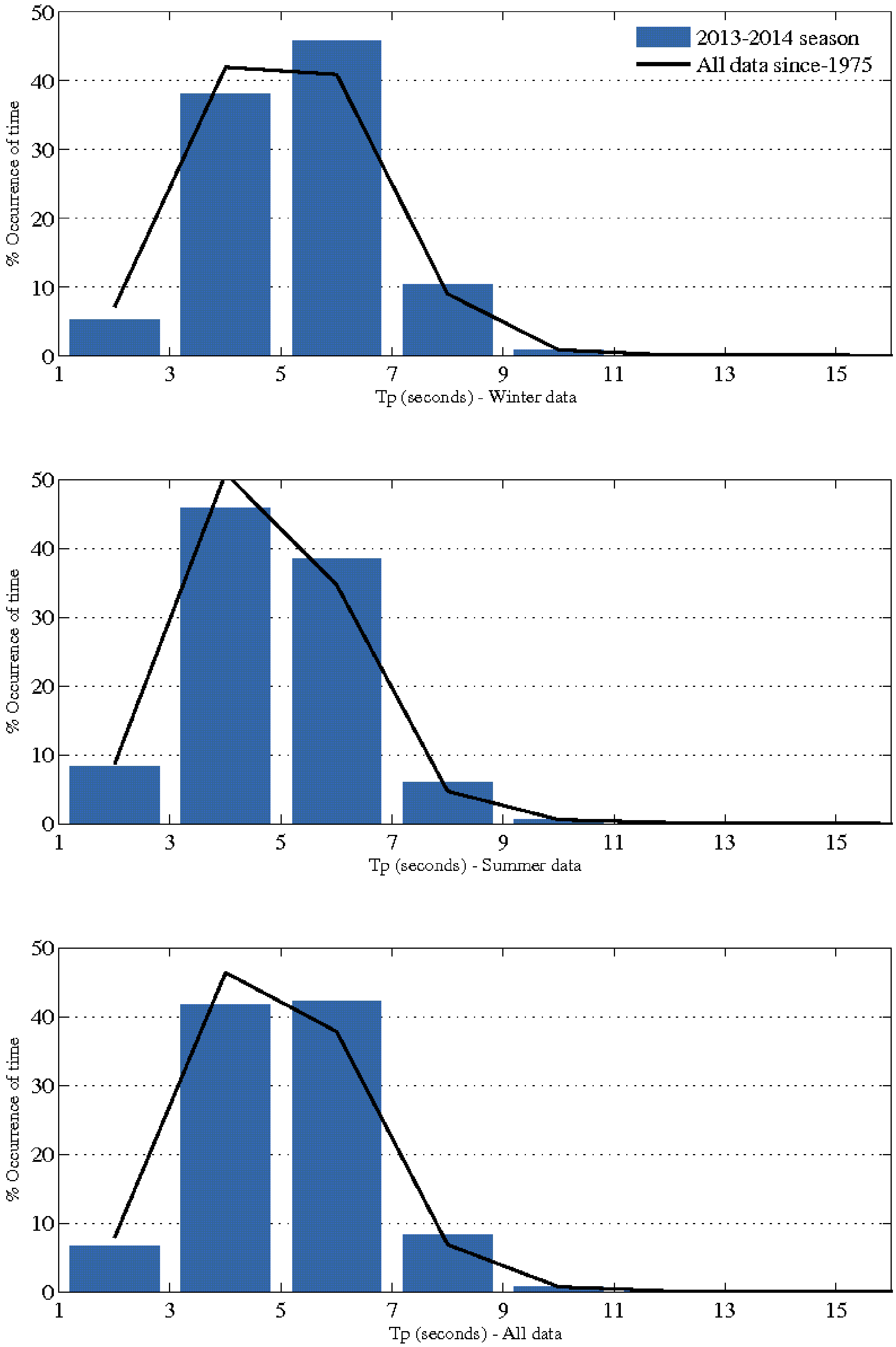


Figure 109 Townsville – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

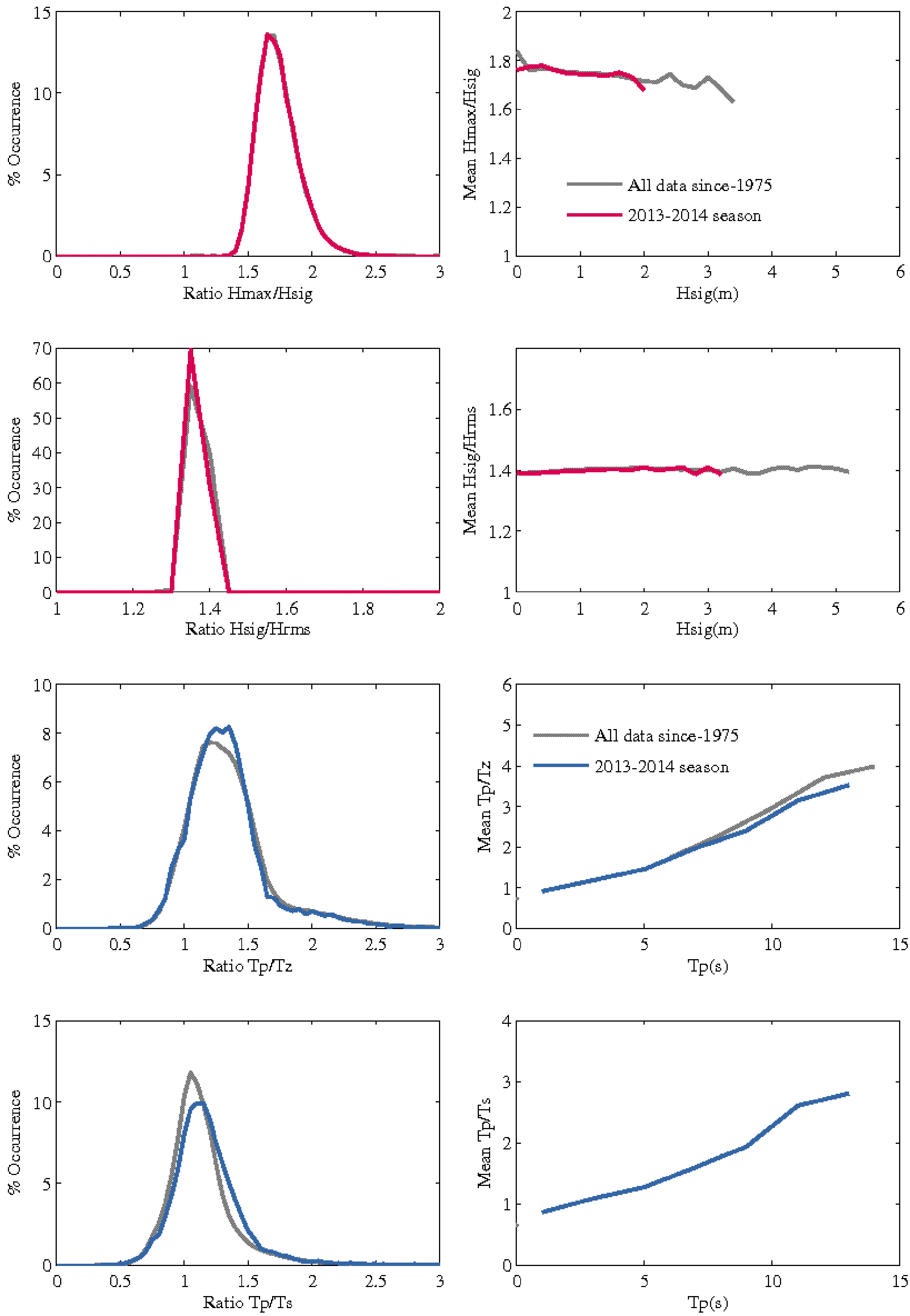
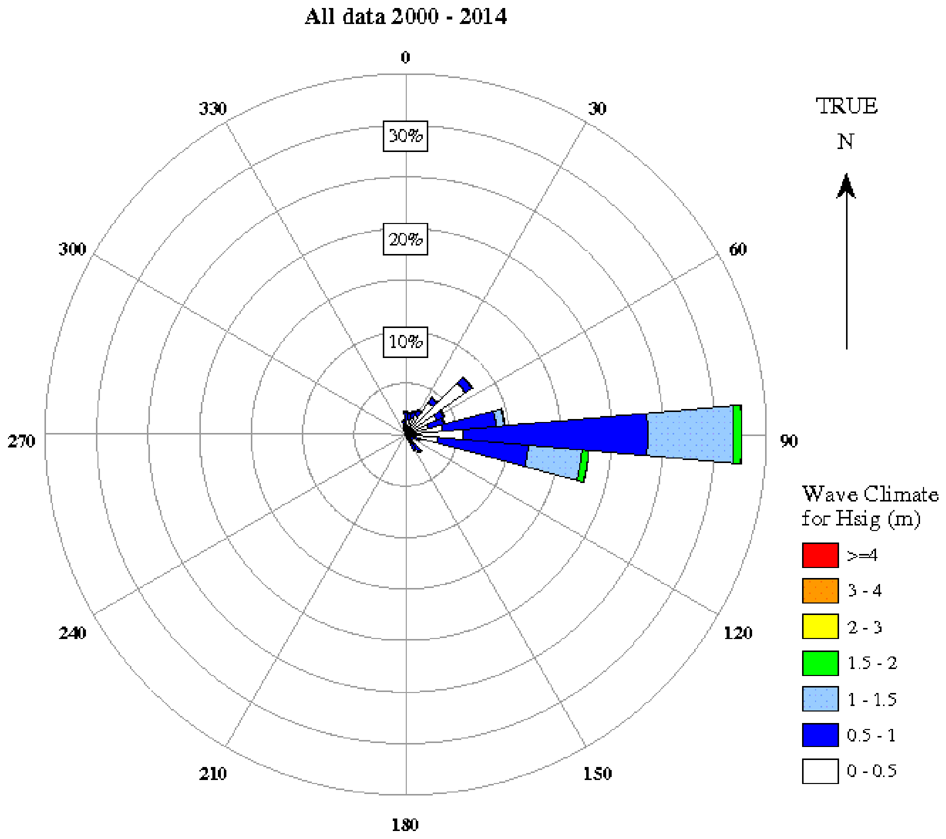


Figure 110 Townsville – Wave parameter relationships



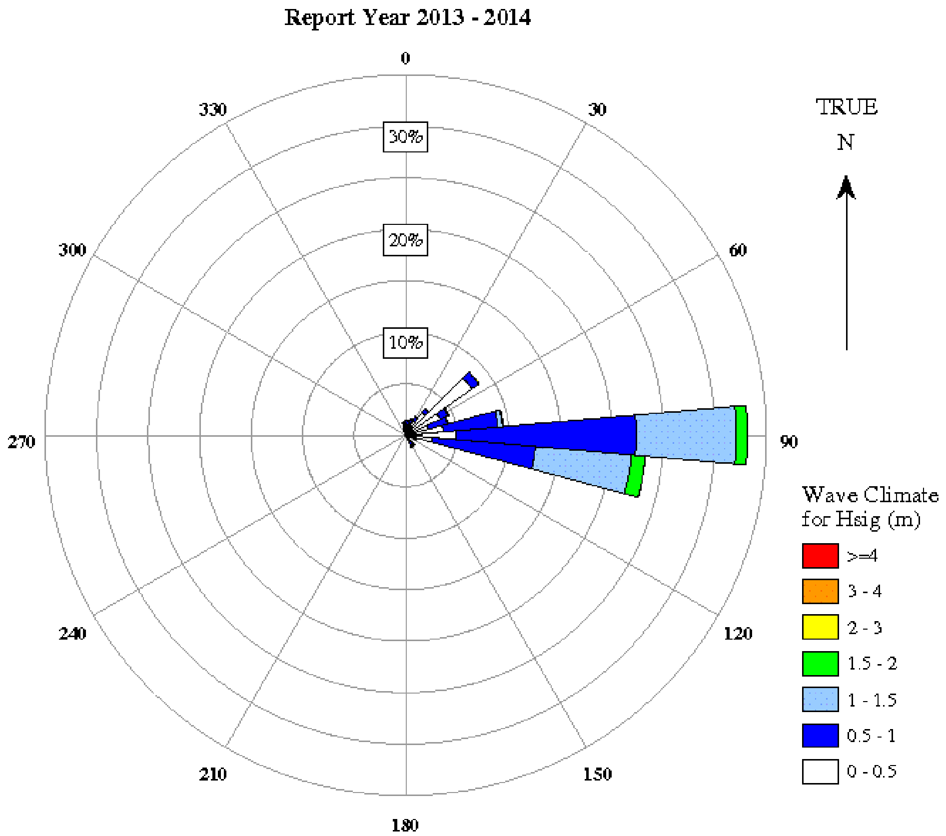


Figure 111 Townsville – Directional wave rose

7.13 Cairns

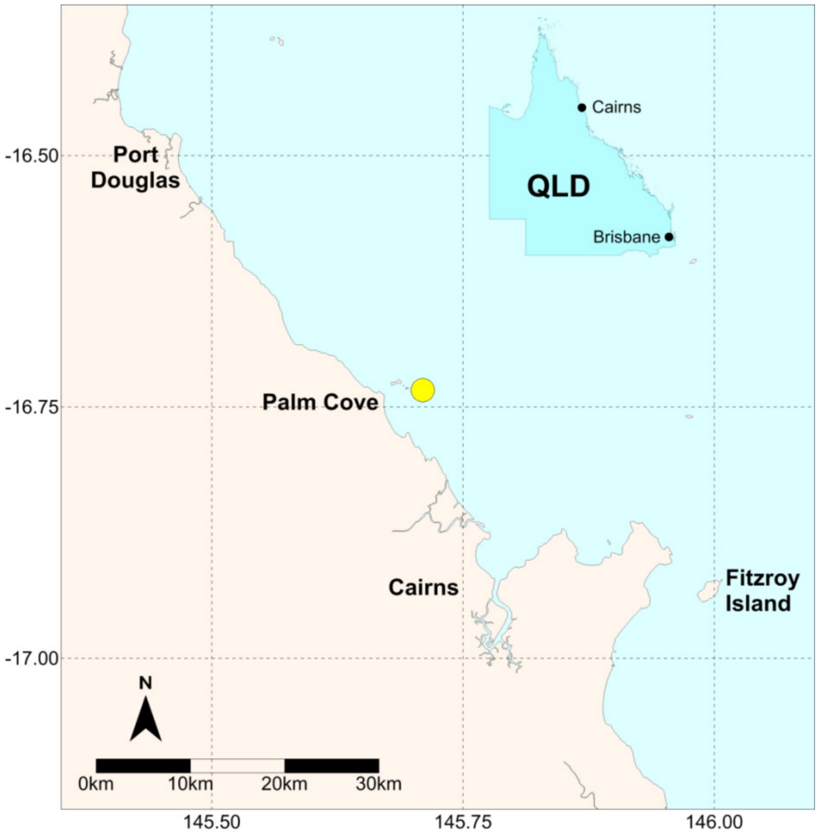


Figure 112 Cairns – Locality plan

Table 52 Cairns – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	04/05/1975	na	307731	39.5
2013 -14	1/11/2013	36.92 days	15747	1

Table 53 Cairns – Buoy deployments for the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
16°43.950'S	145°42.620'E	12	17/05/2013	05/02/2014
16°43.830'S	145.42.910 E	12	05/02/2014	current

7.13.1 Cairns – seasonal overview

The Cairns wave buoy has been operational for 39.5 years. The data recorded for the period November 2013 to October 2014 experienced extended outages during January and late May for a total gaps of 36.92 days, equivalent to 89.9 percent data return. The buoy was replaced once during the reporting period on 5 February 2014 (Table 97).

The largest ever significant wave height (Hsig) and maximum wave height (Hmax) for the buoy were both recorded on 12 April of the reporting period as a result of TC Ita tracking south along the east Queensland coast (Table 98). The prominent increase in wave height from TC Ita is clearly seen in April of the daily wave recordings figure (Figure 113).

Recording of sea surface temperature (SST) failed from January onwards due to change of the buoy to one without a temperature sensor.

With the exception of November, the monthly average Hsig (Figure 115) for summer months was near to one standard deviation (sd) above the historic monthly mean and exceeded +1 sd during April. The percentage exceedance of Hsig for all wave periods (Figure 116) was overall slightly higher for the reporting period than historical data. There was a notable difference in the height of waves occurring less than 0.5 percent of the time, with larger wave heights recorded over the reporting period. This relates back to the influence of TC Ita generating record wave heights for the site.

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. Though there was a higher occurrence of larger waves over the reporting period.

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

Table 54 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 1:00	5
3	11/02/1999 21:00	2.5	23/01/2013 23:00	4.7
4	3/02/2011 4:30	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	3/02/2011 4:00	4.1
7	19/03/1990 8:42	1.9	12/01/2009 7:00	3.4

8	31/01/1977 9:00	1.9	3/01/1979 3:00	3.3
9	12/01/2009 7:00	1.9	4/03/2008 23:30	3.3
10	3/01/1979 3:00	1.8	31/01/1977 9:00	3.2

Table 55 Cairns – Significant meteorological events with threshold Hsig of 1.5 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
12/04/2014 15:30	3.1 (3.4)	4.5 (5.6)	7.7	Tropical Cyclone Ita [990 hPa] passed along the east coast from north to south as a category 1 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.

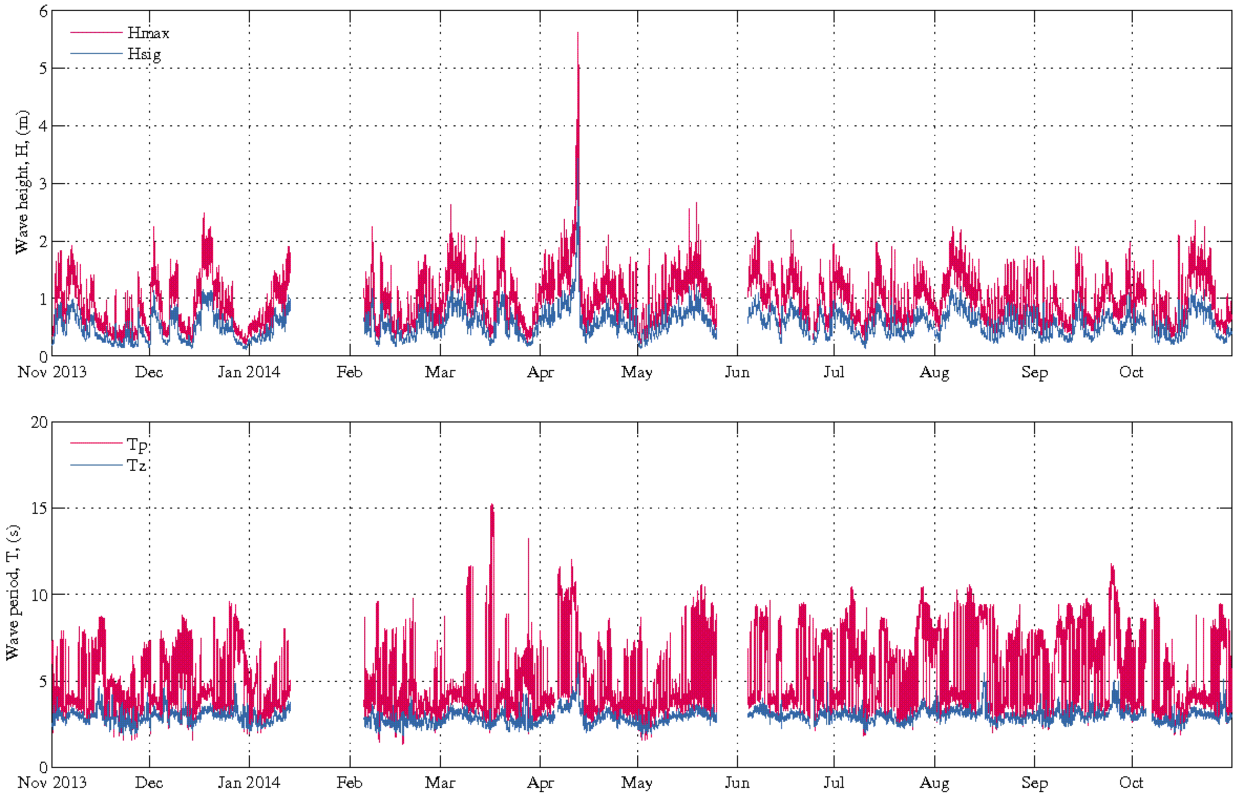


Figure 113 Cairns – Daily wave recordings

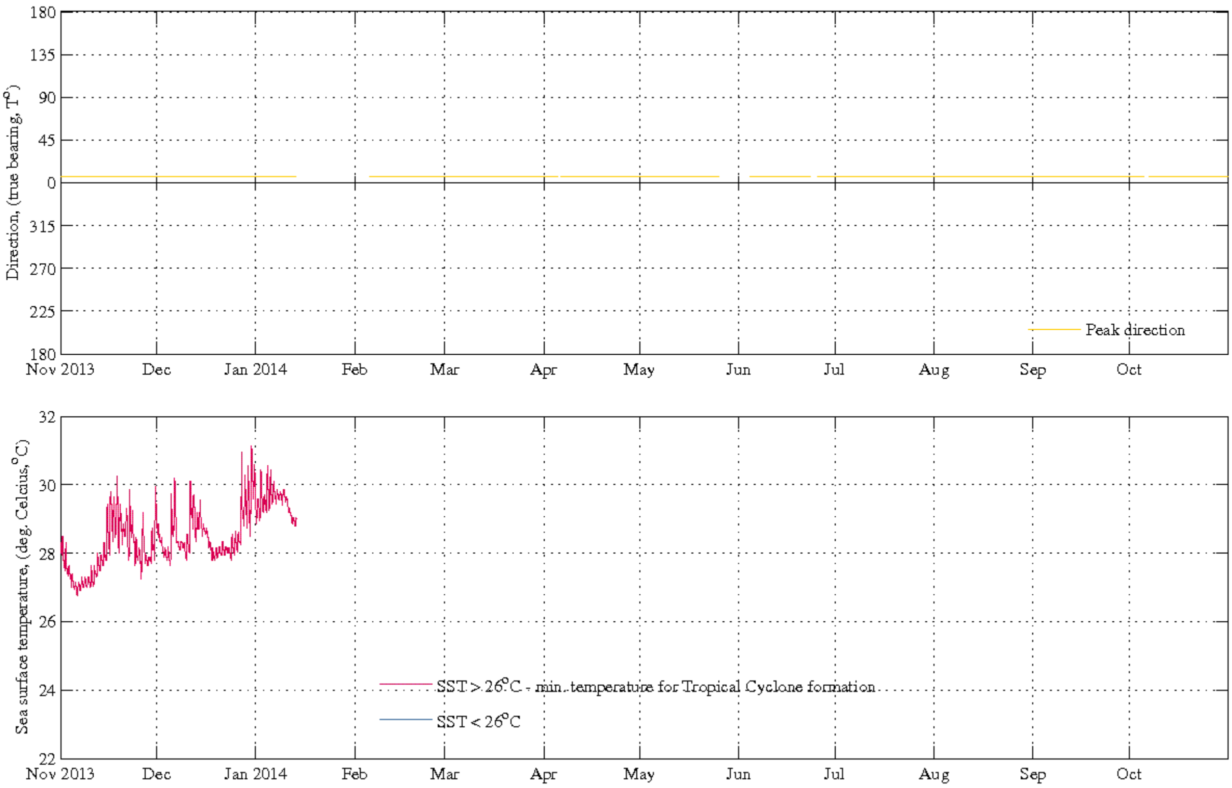


Figure 114 Cairns – Daily Sea surface temperature

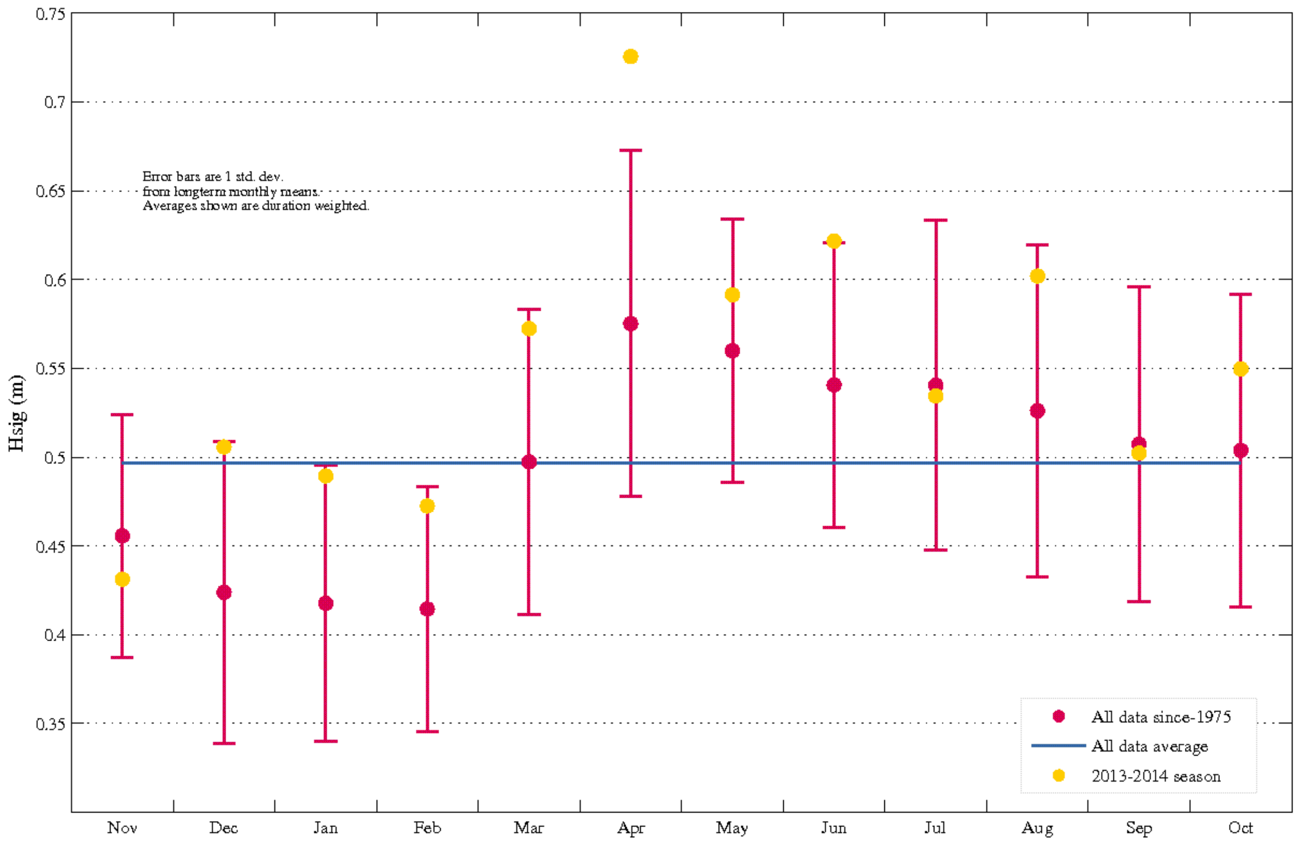


Figure 115 Cairns – Monthly average wave height (Hsig) for seasonal year and for all data

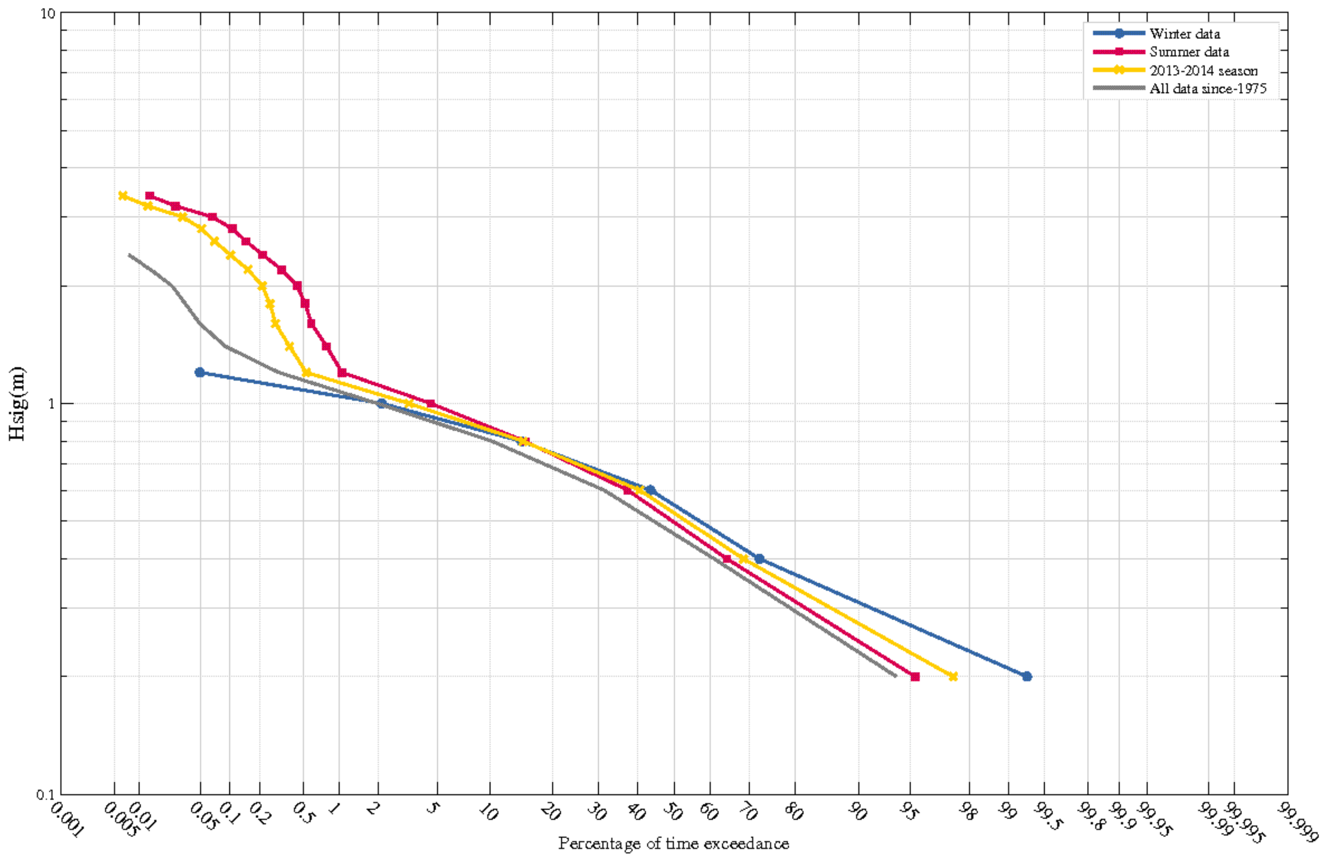


Figure 116 Cairns – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

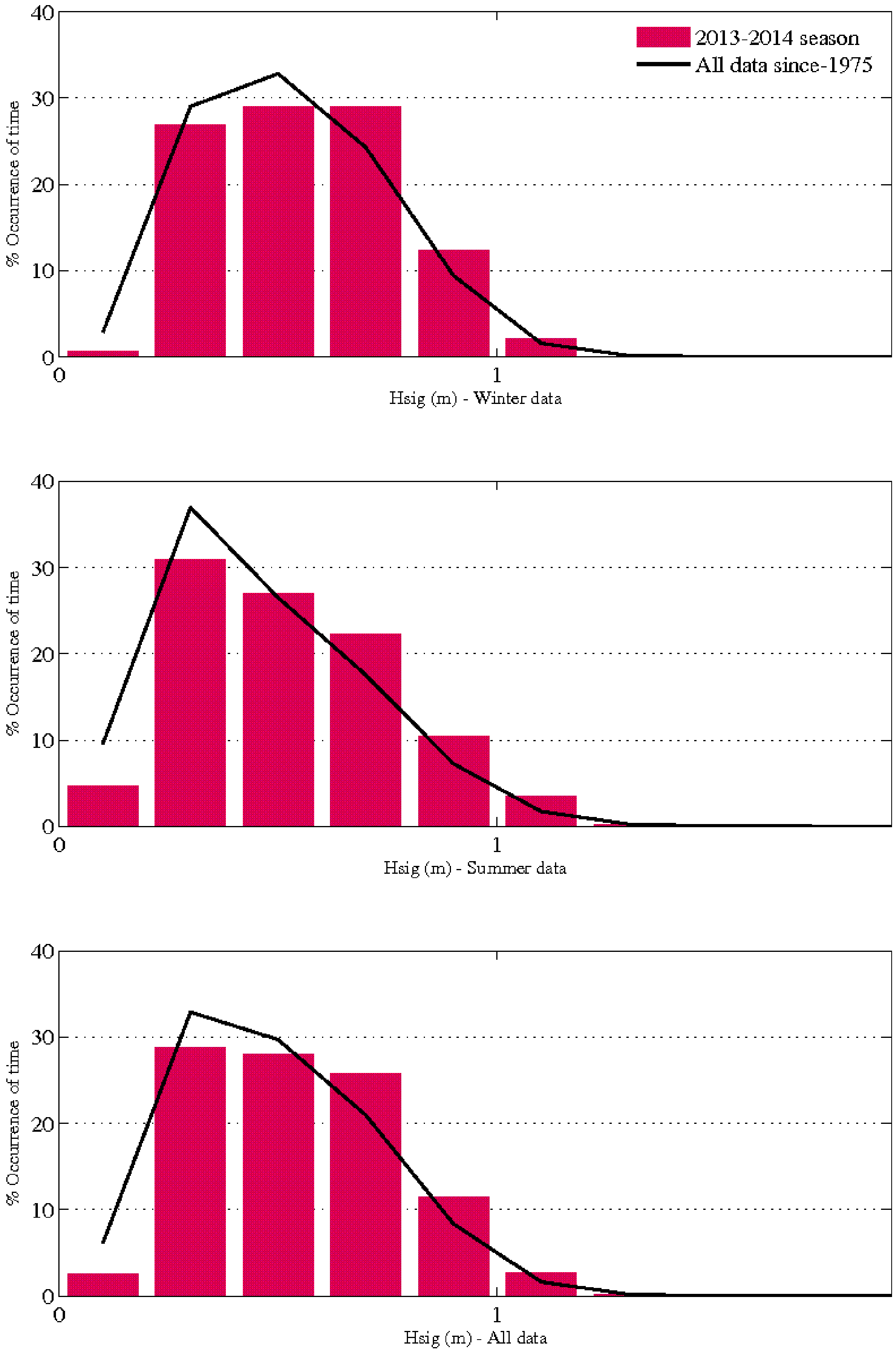


Figure 117 Cairns – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

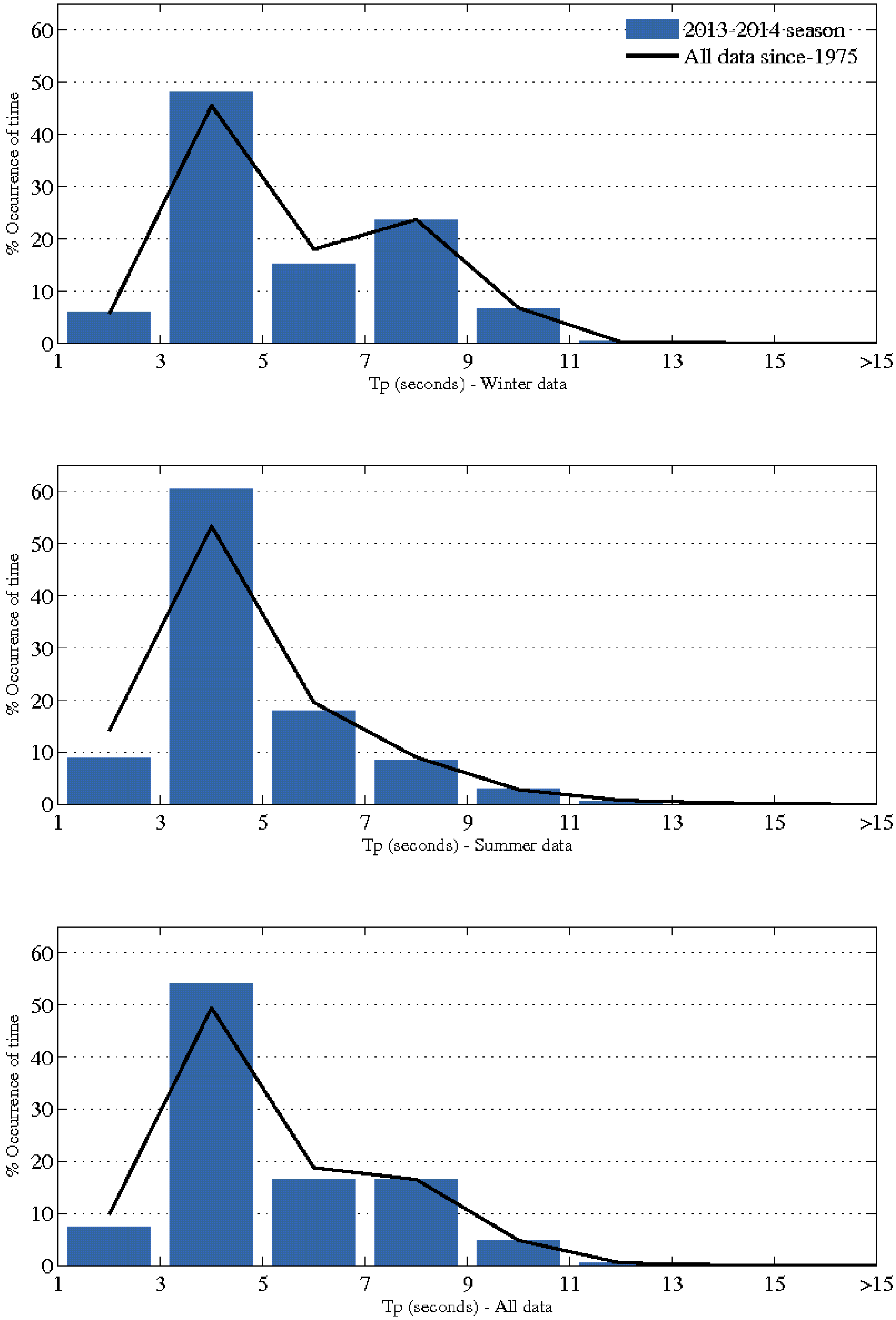


Figure 118 Cairns – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

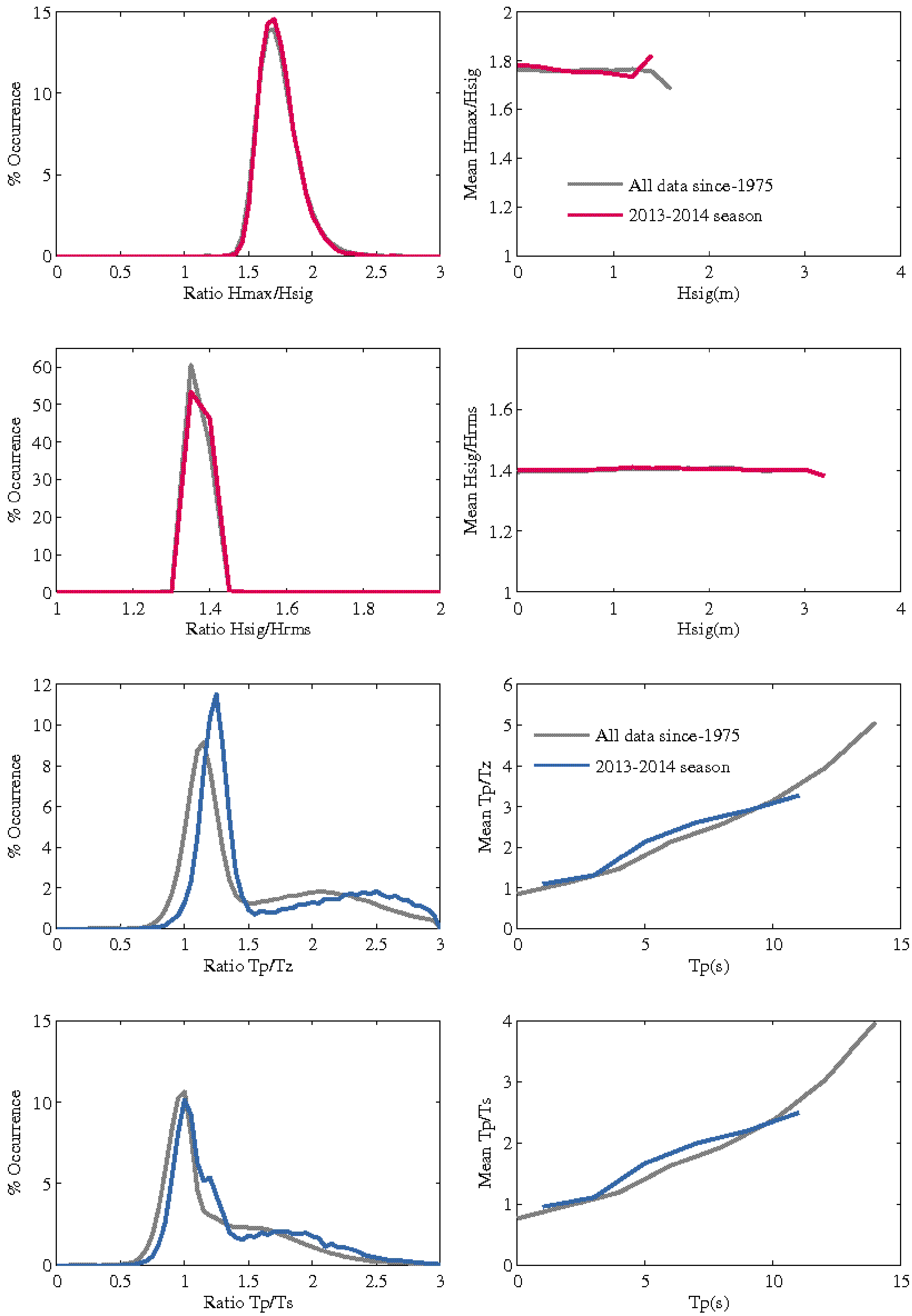


Figure 119 Cairns – Wave parameter relationships

7.14 Albatross Bay

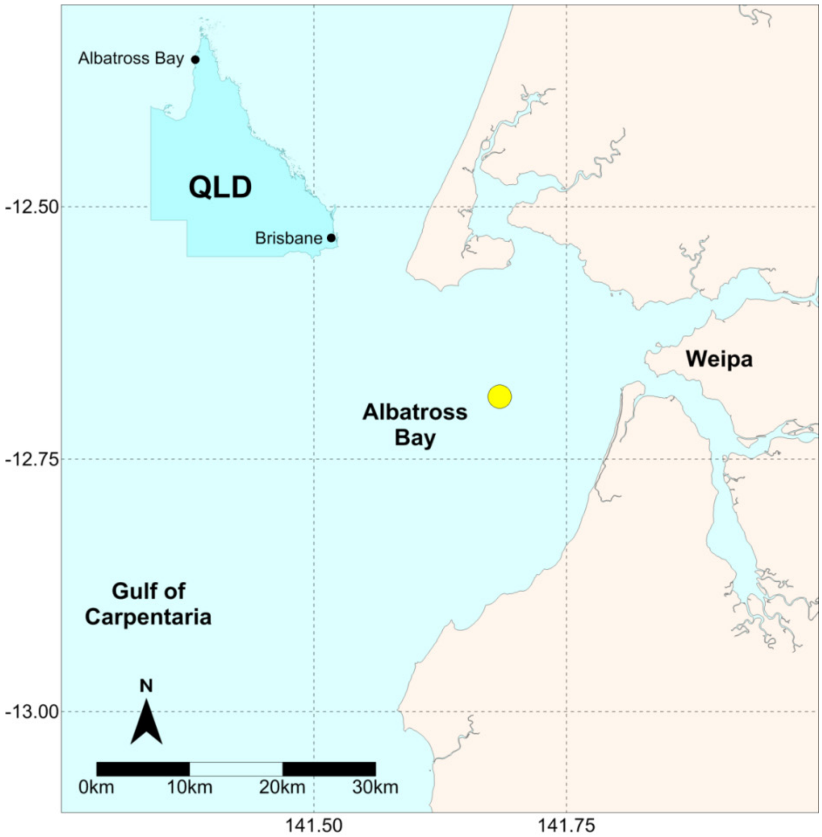


Figure 120 Albatross Bay – Locality plan

Table 56 Albatross Bay – Wave monitoring history

Data period	Start date	Gaps	Number of records	Total years
All data	21/11/2008	0.27 years	97667	5.93
2013 -14	1/11/2013	8.75 days	17099	1

Table 57 Albatross Bay – Buoy deployments for the 2013–14 season

Latitude	Longitude	Depth (m)	Deployed date	Removal date
12°41.295'S	141°41.041'E	10	27/06/2012	11/07/2014
12°41.275'S	141°41.060'E	11	11/07/2014	current

7.14.1 Albatross Bay – seasonal overview

The Albatross Bay wave buoy has been operational for just under six years with an overall data return of 95.4 percent. The data record for the period November 2013 to October 2014 was good, with total gaps of about nine days, equivalent to 97.6 percent data return. The buoy was replaced towards the end of this reporting period on 11 June 2014 (Table 101).

High ranking significant (Hsig) and maximum (Hmax) wave heights were recorded during February and March 2014. Two intense low pressure systems coupling with surface troughs, as well as Tropical Cyclone (TC) Gilian (Table 103), impacted the Gulf of Carpentaria resulting in increased wave activity (Figure 121) for each event. The highest Hsig and Hmax for the recording period of 2.6 m and 5.0 m occurred during the low pressure system and trough on the 19 February 2014.

The Sea Surface Temperature (SST) measured in the buoy hull show the recorded values ranged from 24.5° C to 33° C over the report year. The SST was high enough for tropical cyclone development for most of the year, except for the second half of June through to the first half of September and very early 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).

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 1 percent 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 over 1 m Hsig occurred 7.5 percent of the time during summer, where this was less than 1 percent during winter. Histograms of Hsig (Figure 125) show a higher percentage occurrence for the modal value of the recording period, this was more prevalent in summer. Histograms of Tp (Figure 125) were very similar between this season and the whole record.

The plot of wave direction over the 2013–2014 season (Figure 122) showed a dominant south westerly direction with an occasional swing to either the west of east. 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 58 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	2/02/2012 8:30	2.7	3/02/2012 9:00	5.1

5	19/03/2012 2:30	2.6	19/02/2014 07:30	5.0
6	19/02/2014 6:30	2.6	18/03/2012 19:30	4.3
7	29/12/2011 17:30	2.4	22/01/2011 6:00	4.2
8	2/02/2009 11:00	2	2/02/2009 9:30	4.0
9	09/03/2014 17:00	2.1	3/02/2014 15:30	3.9
10	03/02/2014 16:30	2.1	29/12/2011 18:00	3.8

Table 59 Albatross Bay – Significant meteorological events with threshold Hsig of 1.0 metres

Date	Hs (m)	Hmax (m)	Tp (s)	Event
03/02/2014 16:30	1.9 (2.1)	3.2 (3.9)	8.0	Intense low [995 hPa] and trough extended across the top of north Queensland.
19/02/2014 06:30	2.4 (2.6)	4.2 (5.0)	9.6	An intense low pressure system [1002 hPa] and associated front linked to a surface trough and low in the Gulf of Carpentaria.
09/03/2014 17:00	1.9 (2.1)	3.2 (3.7)	7.9	TC Gillian [999 hPa] was present in the southern Gulf of Carpentaria.

Denotes peak Hsig event

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

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

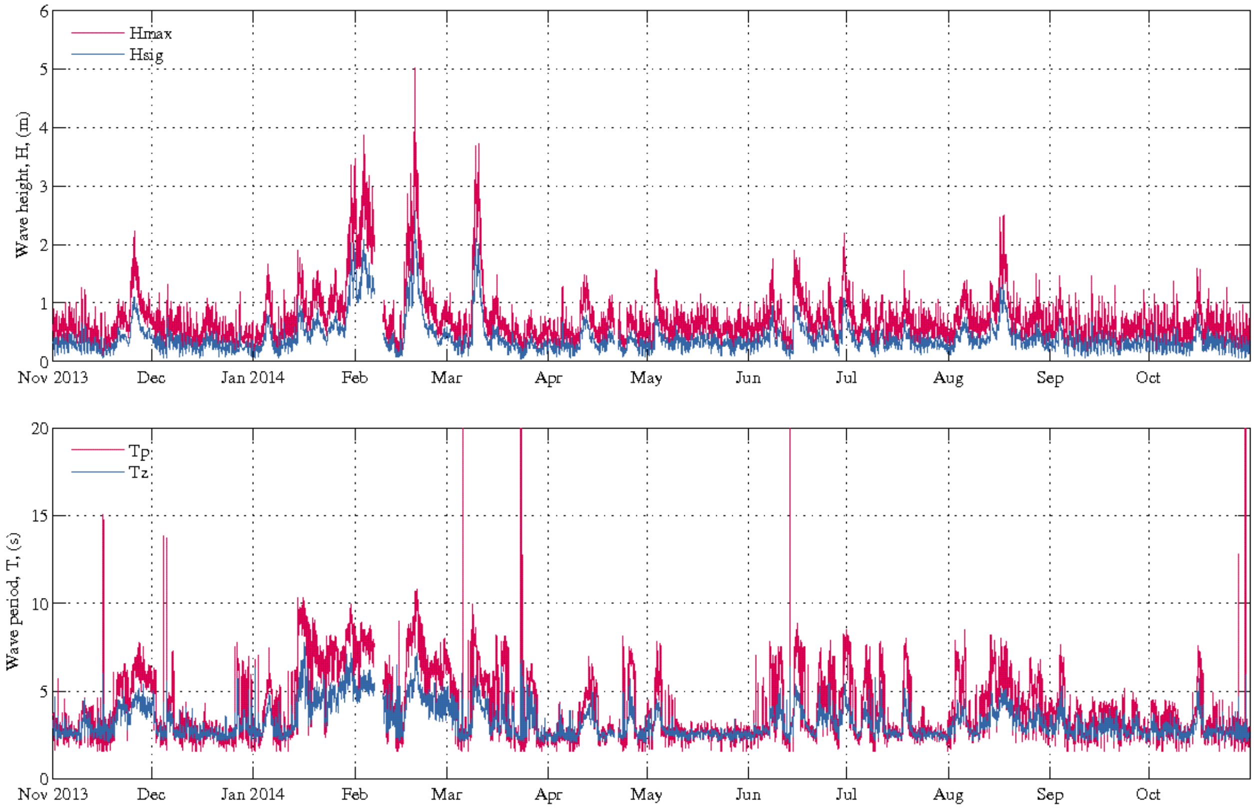


Figure 121 Albatross Bay – Daily wave recordings

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

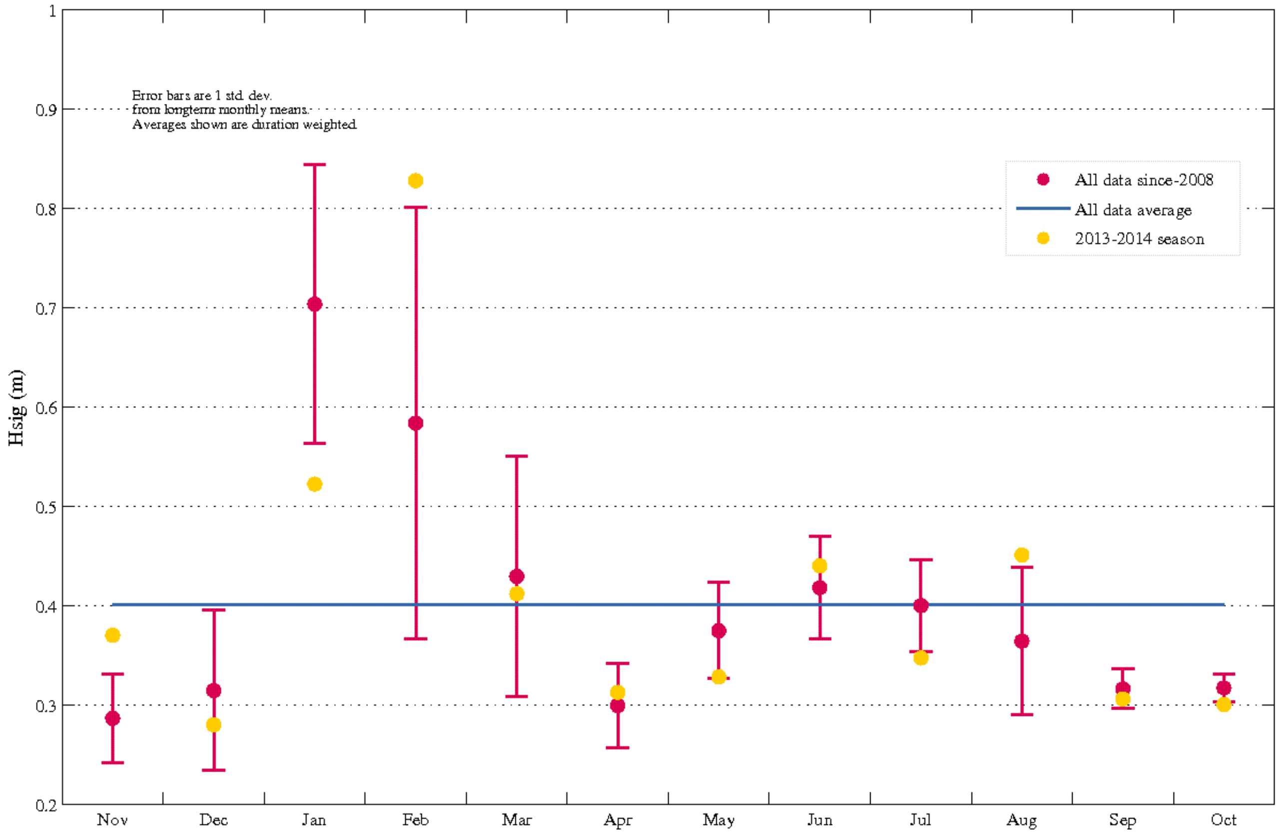


Figure 123 Albatross Bay – Monthly average wave height (Hsig) for seasonal year and for all data

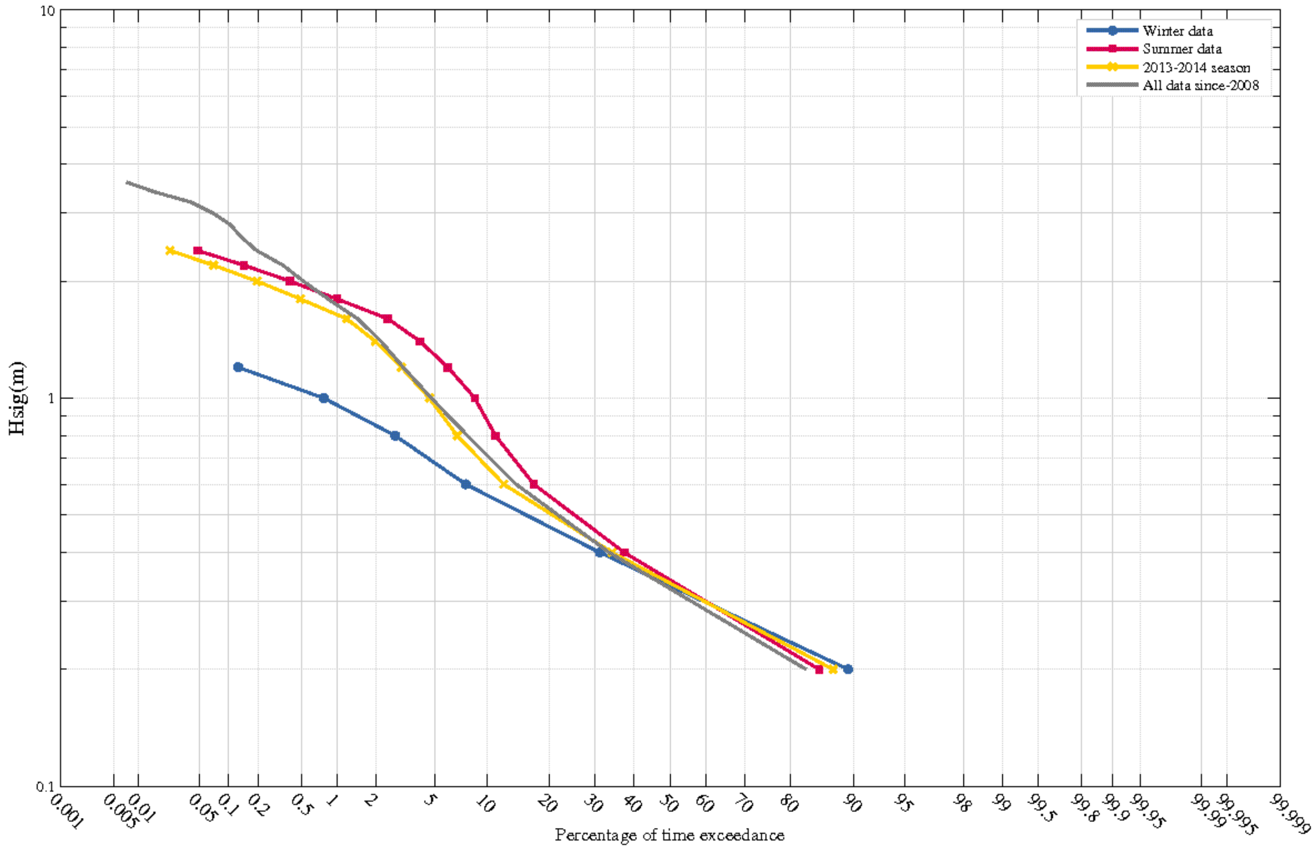


Figure 124 Albatross Bay – Percentage exceedance of wave height (Hsig) for all wave periods (Tp)

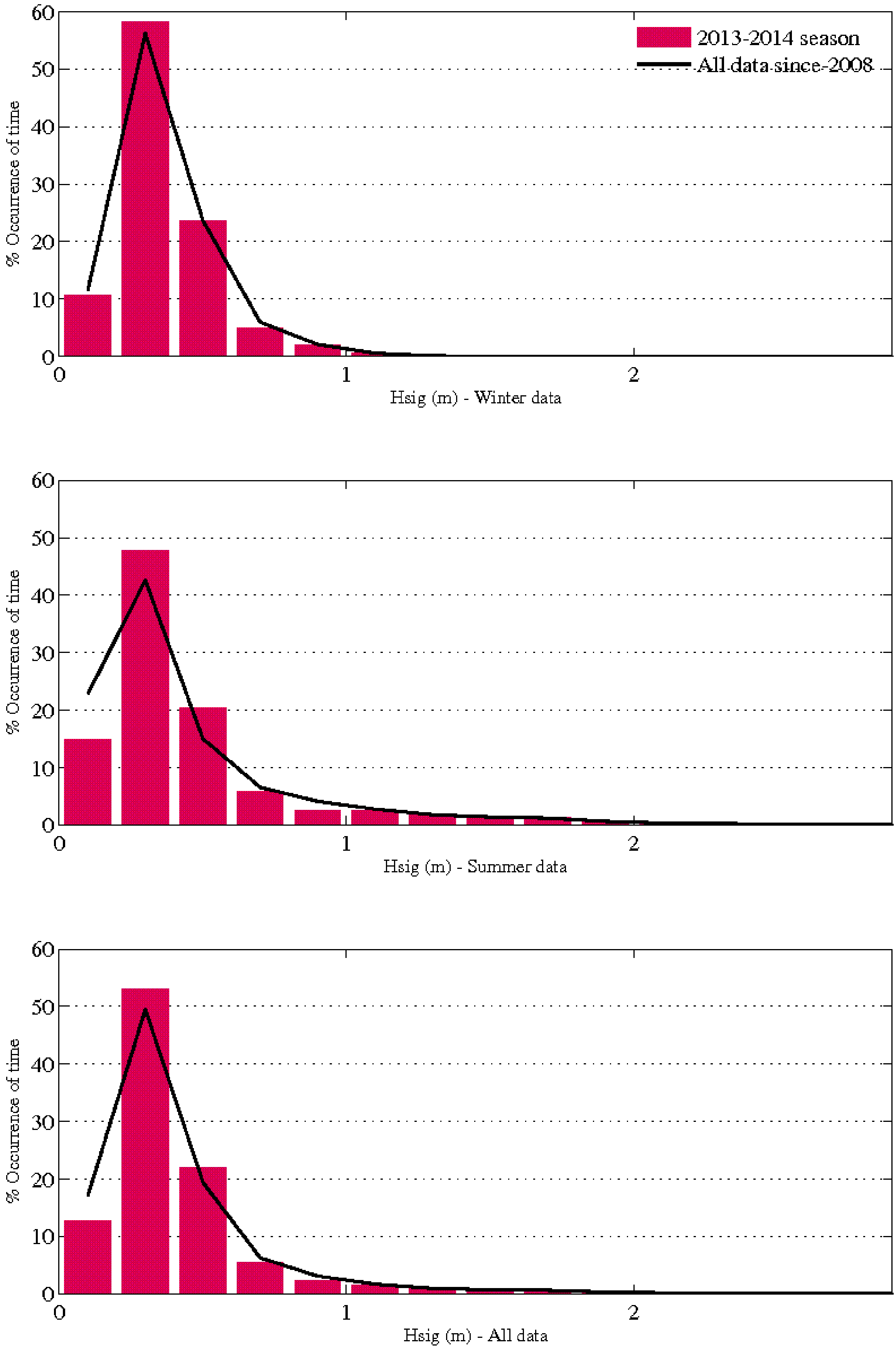


Figure 125 Albatross Bay – Histogram percentage (of time) occurrence of wave heights (Hsig) for all wave periods (Tp)

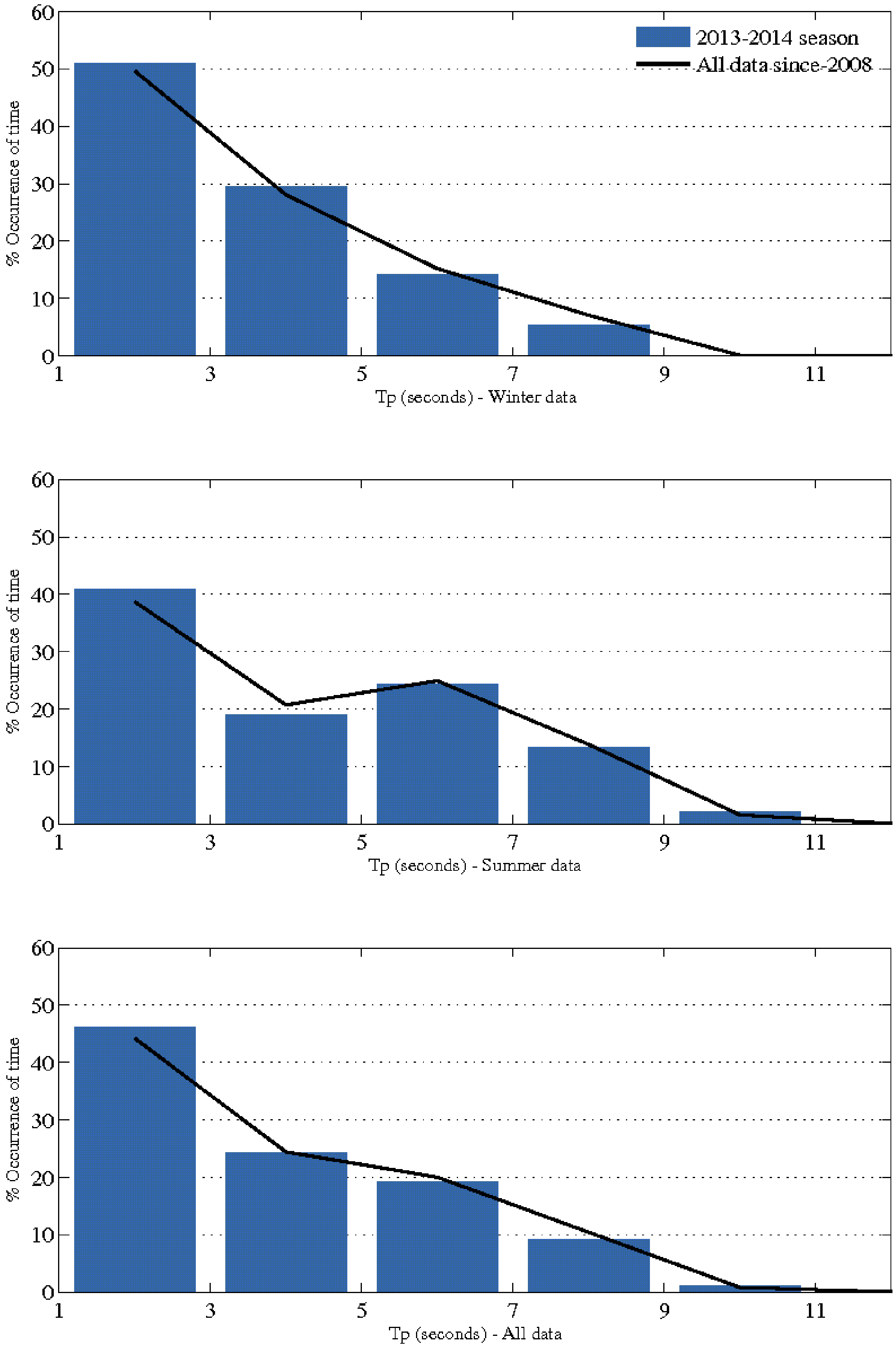


Figure 126 Albatross Bay – Histogram percentage (of time) occurrence of wave periods (Tp) for all wave heights (Hsig)

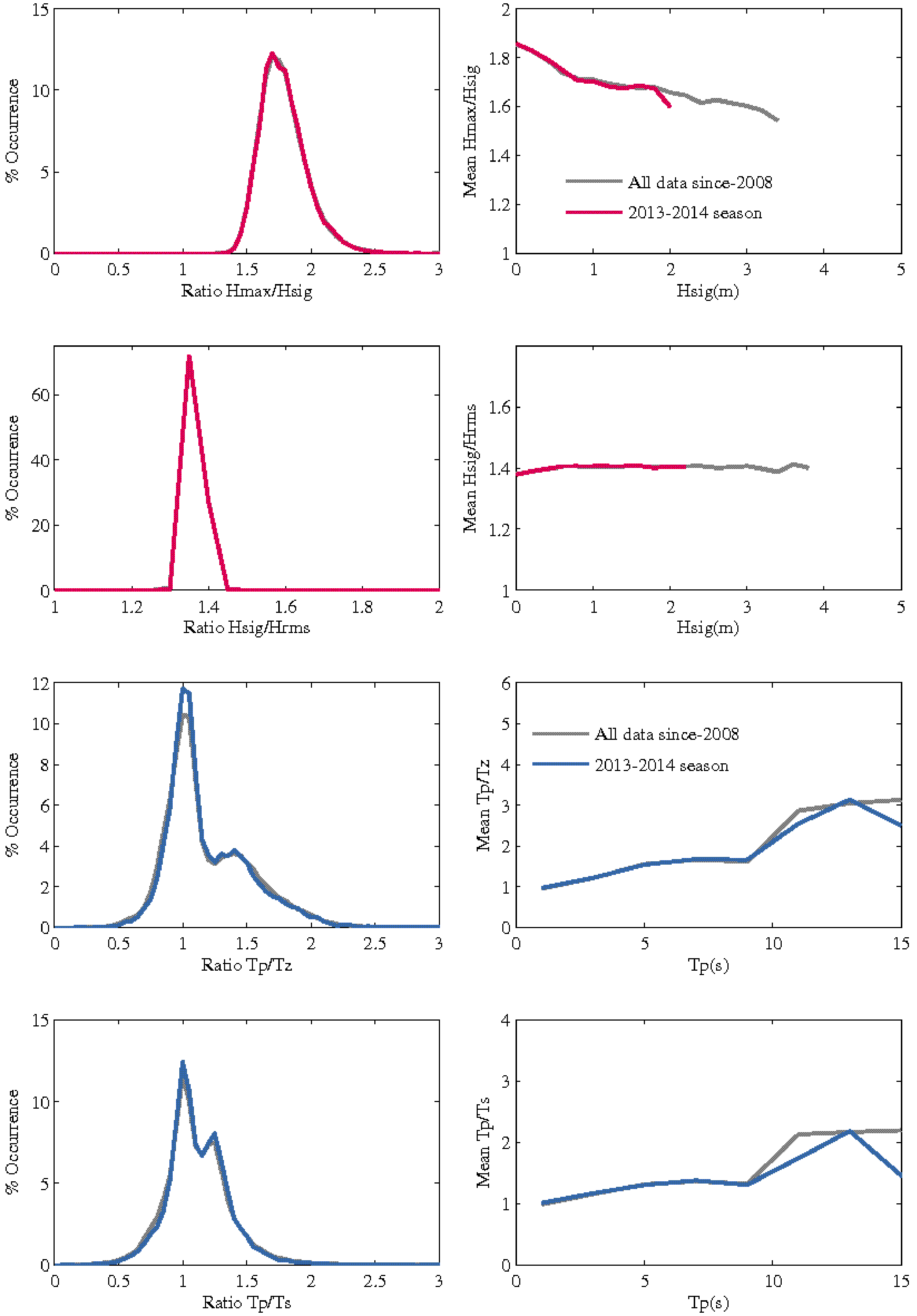
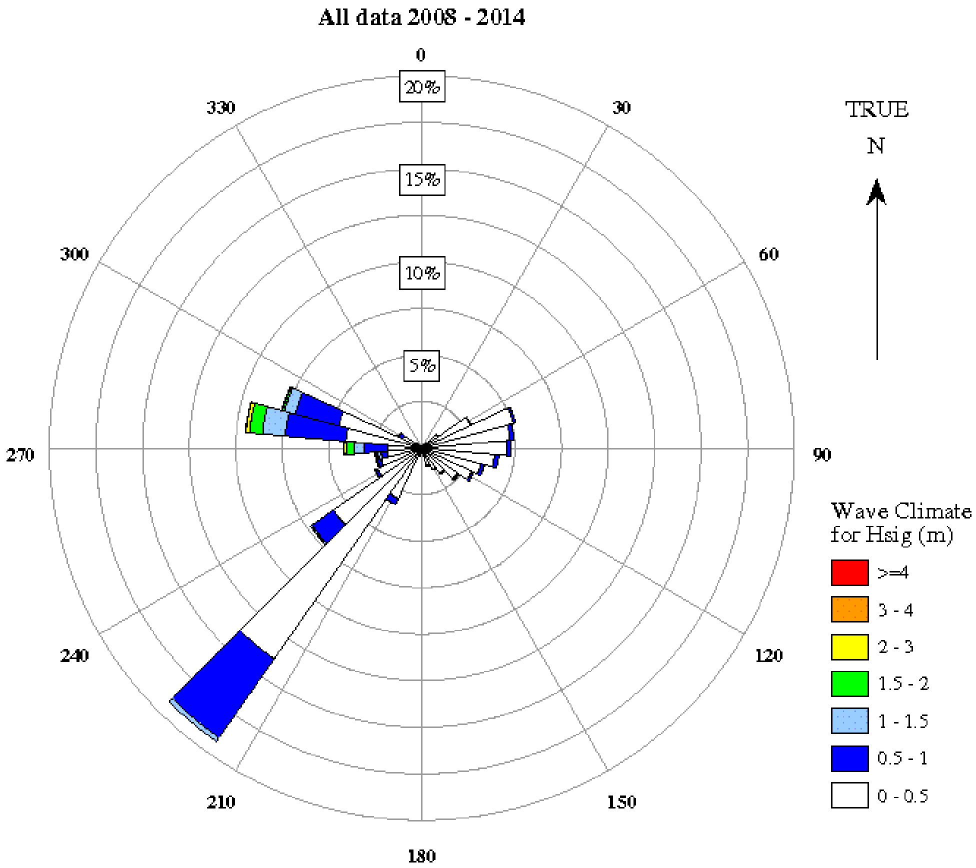


Figure 127 Albatross Bay – Wave parameter relationships



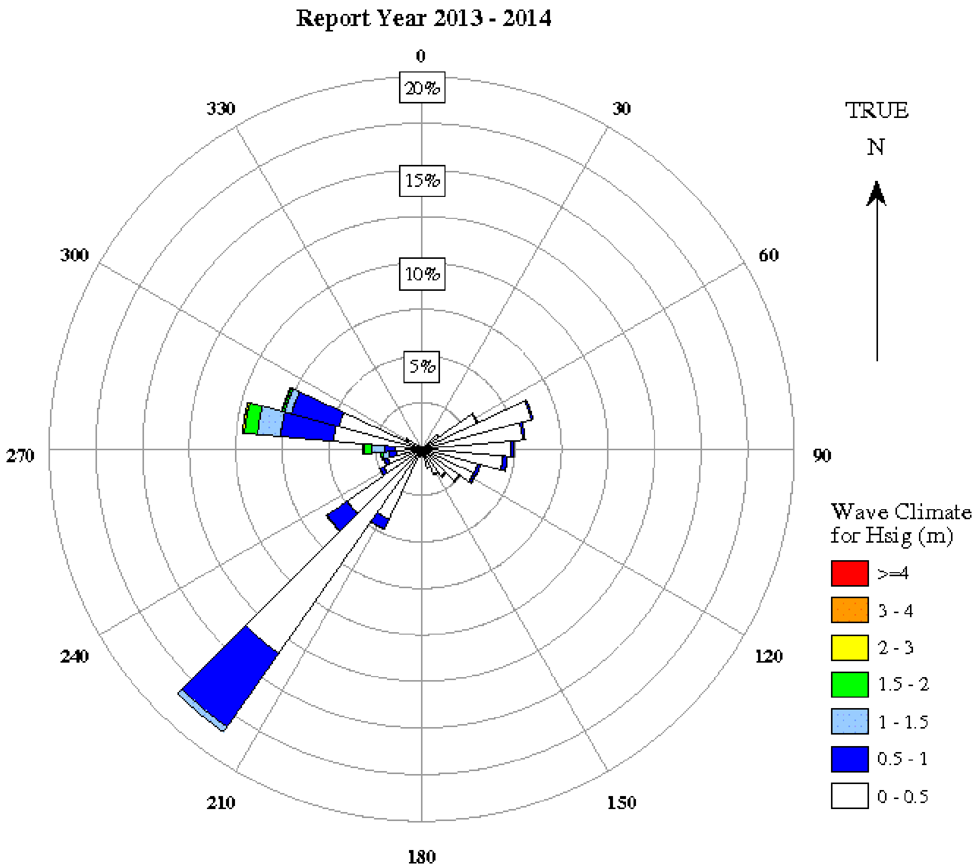


Figure 128 Albatross Bay – Directional wave rose

8 References

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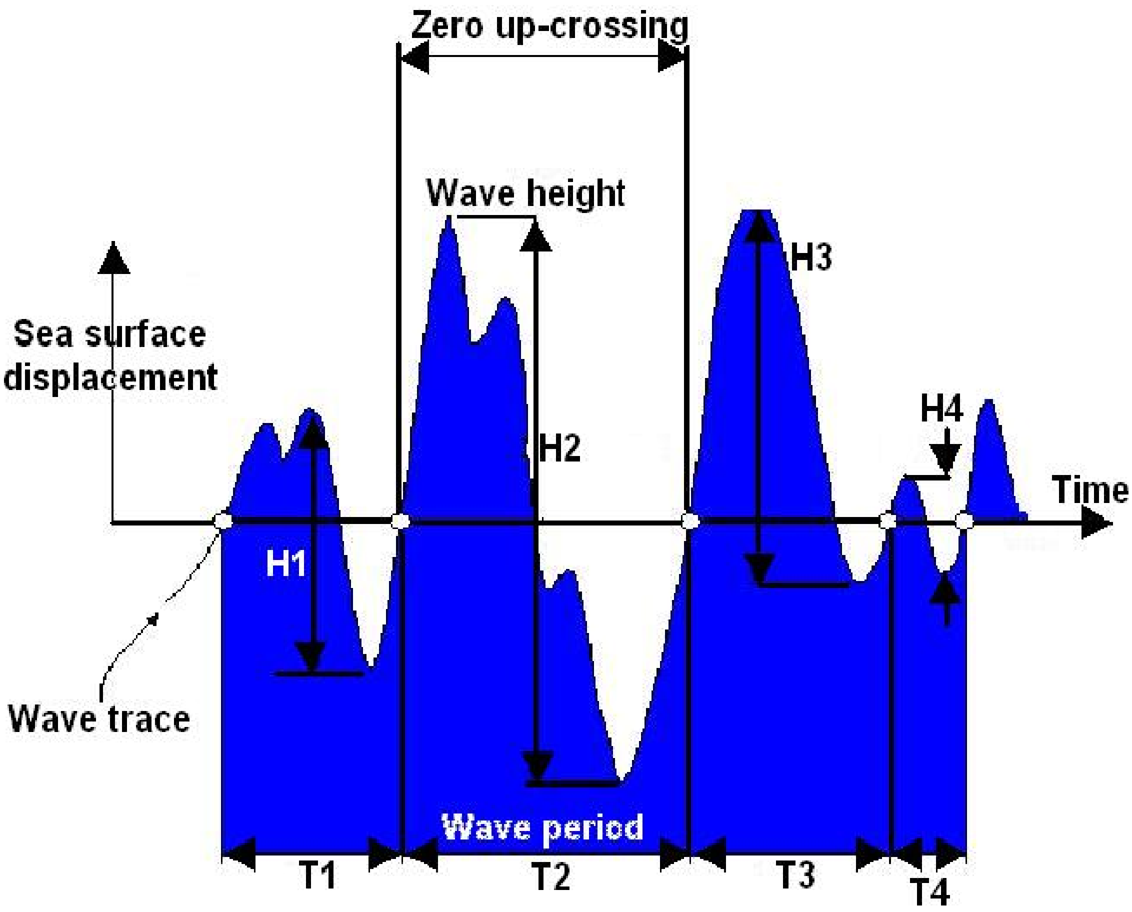
9 Appendix A Zero up-crossing analysis

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
Hsig	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.
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.