The New South Wales Wave Climate Improved Understanding through the Introduction of Directional Wave Monitoring Buoys

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Abstract

Deepwater wave data is routinely collected for the NSW Office of Environment and Heritage by NSW Public Works' Manly Hydraulics Laboratory using a network of wave monitoring buoys. The data comprise long-term wave histories at seven locations along the 1200 kilometre NSW coastline. Data at four of the stations is available for periods of over 35 years and therefore represents one of the most comprehensive wave climate data sets available anywhere in the world. Since the Sydney station was upgraded with a Datawell Directional Waverider buoy in 1992, the buoy network has been progressively converted to directional buoys from 1999 to 2012. An overview of seasonal directional variations along the NSW coast and data rich directional spectra processed by the directional buoys will be presented for the first time. This information will be of great interest to coastal managers and designers, particularly with the increased awareness of the potential impact of climate change on regional wave climates. Predictions of increased storminess, changes to wave direction distributions and the potential impact on coastal processes highlight the need for the continued collection of ocean wave data into the future.

Keywords: wave climate, wave monitoring, directional spectra

1. Introduction

NSW Public Works' Manly Hydraulics Laboratory (MHL) collects deepwater wave data at seven locations along the NSW coast for the NSW Office of Environment and Heritage. The monitoring network is based on the well-known Datawell Waverider buoy system and the development of the wave monitoring network over the years and information on the NSW wave climate and regional wave generation mechanisms has been regularly documented in publications including Webb [8], Webb and Kulmar [9], Kulmar [1], Kulmar et al [2] and Shand et al. [5].

The NSW wave data is accessed by millions of people every year for recreational activities, but its real value in coastal hazard definition, planning, design, forecasting and storm event management is often under recognised. While numerical prediction and hindcasting of waves has vastly improved with global forecast models, these are still limited, particularly in predicting major coastal storm waves. Many years of continuous records, therefore, remain necessary to develop extreme storm statistics for design, and with climate change, ongoing monitoring is increasingly important because changes in both wave height and wave direction can have significant effect on planning lines, serviceability of ports and marinas and the stability of coastal structures.

The NSW Waverider buoy network now includes four stations with over 35 years of data and three stations with over 12 years of directional information and therefore represents one of the most comprehensive wave climate data sets anywhere in the world. Updates of previously published wave climate information are presented in the paper. An overview of seasonal wave directional variations along the NSW coast and rich directional spectra information will be documented for the first time.

2. The NSW Wave Monitoring Buoy Network

The locations of the NSW Waverider buoy stations are shown in Figure 1.

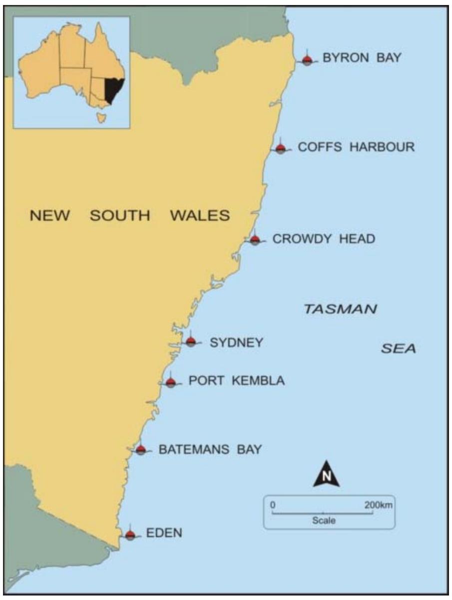

Figure 1 NSW Deepwater Waverider buoy stations maintained by Manly Hydraulics Laboratory for the Office of Environment and Heritage

To provide deepwater data the buoys are typically moored in a water depth over 70 m, between 8 and 12 km from the shoreline. Since the Sydney station was upgraded with a Datawell Directional Waverider buoy in 1992, the buoy network has been progressively converted to directional buoys from 1999 to 2012. Table 1 provides details of commissioning dates for the buoy network.

Table 1 NSW Waverider Buoy Stations

Wave Station	Date Site Commissioned	Directional Buoy Deployed
Byron Bay	14-Oct-1976	26-Oct-1999
Coffs Harbour	26-May-1976	14-Feb-2012
Crowdy Head	10-Oct-1985	19-Aug-2011
Sydney	17-Jul-1987	03-Mar-1992
Port Kembla	07-Feb-1974	20-Jun-2012
Batemans Bay	27-May-1986	23-Feb-2001
Eden	08-Feb-1978	16-Dec-2011

3. NSW Wave Climate

3.1 General

In recent years information published on the NSW wave climate has mainly focussed on storms and extreme waves and includes Shand et al. [5], Watson et al. [7] and WRL [10]. However, the last overview which included a detailed summary of wave height, period and direction was published in 2005 by Kulmar et al. [2]. Since then, a further seven years of data has been collected including the early directional data now available at the Coffs Harbour, Crowdy Head, Port Kembla and Eden stations.

3.2 Wave Height

Significant wave height (Hsig) exceedance is presented in Table 2 and Figure 2.

In general, the exceedance distribution of Hsig is similar along the length of the NSW coast except in the case of Batemans Bay. There is an increase in variation for Hsig > 5 m and this result may be explained by the loss of storm data due to equipment failure, the differing data capture rates and length of record between individual stations.

Table 2 and Figure 2 clearly show the lower wave height distribution at Batemans Bay. An investigation of the lower height distribution at Batemans Bay was published in MHL [4] and identified that the lower wave climate was attributed to a combination of land mass sheltering from Victoria, Tasmania and New Zealand and variation in the distribution of wave generating wind fields in the Tasman Sea.

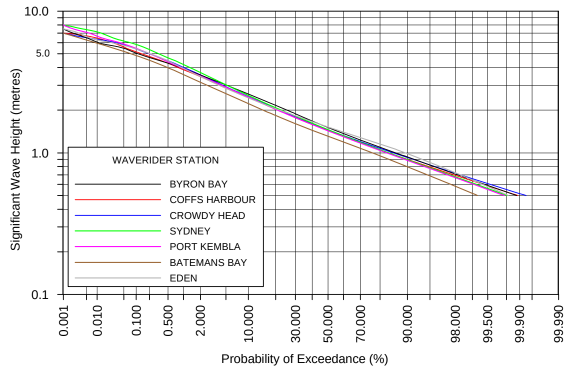

Figure 2 Wave Height Exceedance for All Stations to March 2013

Table 2 NSW Wave Height Exceedance - All Stations to March 2013

Hsig (m)	Byron Bay (%)	Coffs Harbour (%)	Crowdy Head (%)	Sydney (%)	Port Kembla (%)	Batemans Bay (%)	Eden (%)
0.5	99.883	99.890	99.930	99.807	99.776	99.206	99.817
1.0	86.303	83.627	85.419	83.774	82.919	76.331	89.467
1.5	50.651	45.379	46.931	46.922	45.021	36.181	51.832
2.0	25.570	21.020	22.057	22.716	20.935	14.864	21.965
2.5	11.823	9.289	9.875	10.577	9.629	6.178	9.053
3.0	5.071	4.088	4.514	5.249	4.347	2.579	3.982
3.5	2.208	1.850	2.171	2.597	1.963	1.114	1.873
4.0	0.891	0.797	1.015	1.297	0.887	0.491	0.930
4.5	0.322	0.349	0.480	0.661	0.423	0.202	0.470
5.0	0.112	0.135	0.203	0.320	0.208	0.083	0.213
5.5	0.048	0.057	0.084	0.168	0.094	0.026	0.085
6.0	0.011	0.026	0.032	0.071	0.040	0.009	0.025
6.5	0.005	0.009	0.005	0.026	0.013	0.003	0.006
7.0	0.002	0.001	0.001	0.013	0.006	0.001	0.003
7.5	0.001			0.004	0.002		0.001
8.0				0.003	0.002		
Avg. Hsig(m)	1.67	1.58	1.61	1.62	1.58	1.44	1.65
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	03-Mar-1992	07-Feb-1974	27-May-1986	08-Feb-1978
Record (yrs)	36.48	36.87	27.49	21.09	39.17	26.86	35.16
No. Records	199,912	226,611	205,994	152,671	231,977	212,968	219,358
Capture (%)	73.4	85.03	85.51	86.15	83.48	90.47	83.30

3.3 Wave Period

Peak spectral wave period (TP1) occurrence displays a good correlation along the NSW coast for all seven stations as shown in Table 3 and Figure 3.

The distribution of wave period clearly illustrates the overwhelming dominance of ocean swell conditions with TP1 > 6 seconds occurring over 90% of the time at all stations. The average TP1 is also similar being between 9 and 10 seconds while the incidence of long periods with TP1 > 14 seconds is less than 5% at all stations.

3.4 Wave Direction

3.4.1 Overview

Since the deployment of a Directional Waverider buoy in March 1992 off Sydney the growing database of wave direction information is greatly improving the knowledge and understanding of this important wave parameter. Early analysis of wave direction recorded by the Sydney buoy was documented in Kulmar [1] and Lord and Kulmar [3] and compared the Directional Waverider buoy data with wave direction datasets based on daily observed and hindcast directional estimates. These early studies indicated that the buoy measurements differed considerably from the then widely accepted observed and hindcast distributions. It was concluded that the observed and hindcast information greatly overestimated the occurrence of NNE and NE wave directions and underestimated the SSE and South directions. The introduction of the directional buoys has identified that the predominant wave energy along the NSW coast is from the SSE rather from the earlier assumed SE direction. A summary of wave direction occurrence based on hourly directional records for all Waverider stations is provided in Table 4.

Wave height (Hsig) direction roses for all available data for all seven Waverider stations, including the early data from the recently upgraded directional stations at Coffs Harbour, Crowdy Head, Port Kembla and Eden, are presented in Figure 4. Interestingly, in general, whilst the wave height and period distributions do not display significant variation between the seven stations, the wave height and directional roses certainly indicate differing wave direction climates for the NSW north, central and south coast regions. For instance, the three northern stations at Byron Bay, Coffs Harbour and Crowdy Head clearly indicate more wave energy arriving from the east to ESE sector than the southern stations. On the other hand, Sydney, Port Kembla and Batemans Bay display more predominant wave energy from the SE to SSE directions than the northern stations. Interestingly, the first year of wave direction data from Eden indicates substantially more wave activity from the NNE to NE sector and from the South to SSW sector than the next northern station at Batemans Bay. Longer datasets will be required for the recently established directional stations to confirm and improve the confidence of these early results, however, the significantly different directional distribution displayed by the early Eden dataset will be keenly watched as new data is added.

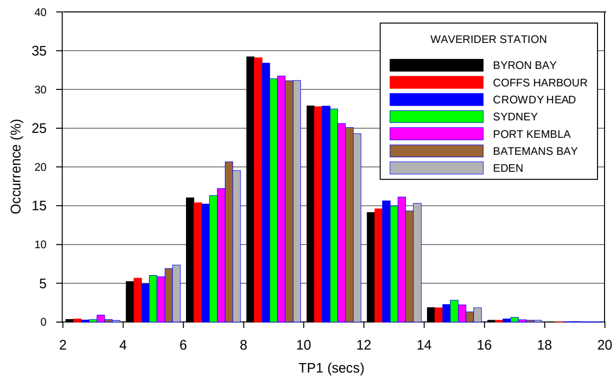

Figure 3 Wave Period Occurrence for All Stations to March 2013

Table 3 Wave Period Occurrence - All Stations to 31 March 2013

TP1 (sec)	Byron Bay (%)	Coffs Harbour (%)	Crowdy Head (%)	Sydney (%)	Port Kembla (%)	Batemans Bay (%)	Eden (%)
2 - 3.99	0.357	0.406	0.261	0.335	0.903	0.333	0.229
4 - 5.99	5.232	5.672	4.911	6.011	5.841	6.892	7.364
6 - 7.99	16.035	15.369	15.229	16.308	17.212	20.657	19.547
8 - 9.99	34.212	34.081	33.426	27.481	31.732	31.115	31.155
10 - 11.99	27.888	27.780	27.858	31.390	25.635	25.097	24.302
12 - 13.99	14.131	14.593	15.623	14.990	16.127	14.340	15.302
14 - 15.99	1.879	1.843	2.254	2.824	2.225	1.315	1.848
16 - 17.99	0.254	0.246	0.419	0.612	0.307	0.242	0.238
18 - 19.99	0.014	0.011	0.020	0.045	0.018	0.010	0.015
Average T_{P1}	9.60	9.60	9.73	9.76	9.59	9.37	9.43
Start Date	14-Oct-1976	26-May-1976	10-Oct-1985	03-Mar-1992	07-Feb-1974	27-May-1986	08-Feb-1978
Record (yrs)	36.48	36.87	27.49	21.09	39.17	26.86	35.16
No. Records	199,912	226,611	205,994	152,671	231,977	212,968	219,358
Capture (%)	73.40	85.03	85.51	86.15	83.48	90.47	83.30

Table 4 Wave Direction Occurrence – All Stations to 31 March 2013

Wave Direction	Byron Bay (%)	Coffs Harbour (%)	Crowdy Head (%)	Sydney (%)	Port Kembla (%)	Batemans Bay (%)	Eden (%)
NNE	2.634	2.690	0.197	0.115	0.670	0.048	7.863
NE	2.605	4.874	3.703	3.058	3.759	2.399	8.285
ENE	4.722	6.446	6.670	9.181	9.900	10.441	7.527
East	14.363	15.782	17.186	11.181	10.923	12.974	7.971
ESE	15.776	15.782	17.414	10.490	10.718	12.796	8.080
SE	18.969	16.436	16.921	16.626	19.185	21.995	10.950
SSE	26.250	26.828	23.757	29.481	27.242	30.503	16.744
South	12.992	9.442	12.247	18.289	14.533	8.324	17.741
SSW	1.060	1.277	1.639	1.169	1.191	0.401	12.293
SW	0.118	0.211	0.258	0.082	0.093	0.021	1.516
Avg Dirn (° T.N)	128.65	123.74	127.47	134.42	132.48	127.83	128.90
Start Date	26-Oct-1999	14-Feb-2012	19-Aug-2011	03-Mar-1992	20-Jun-2012	23-Feb-2001	16-Dec-2011
Record (years)	13.44	1.13	1.62	21.09	0.78	12.10	1.29
No. Records	87,039	9,479	13,179	152,671	5,374	94,658	9,233
Capture (%)	73.87	95.91	92.91	86.15	79.43	89.29	80.78

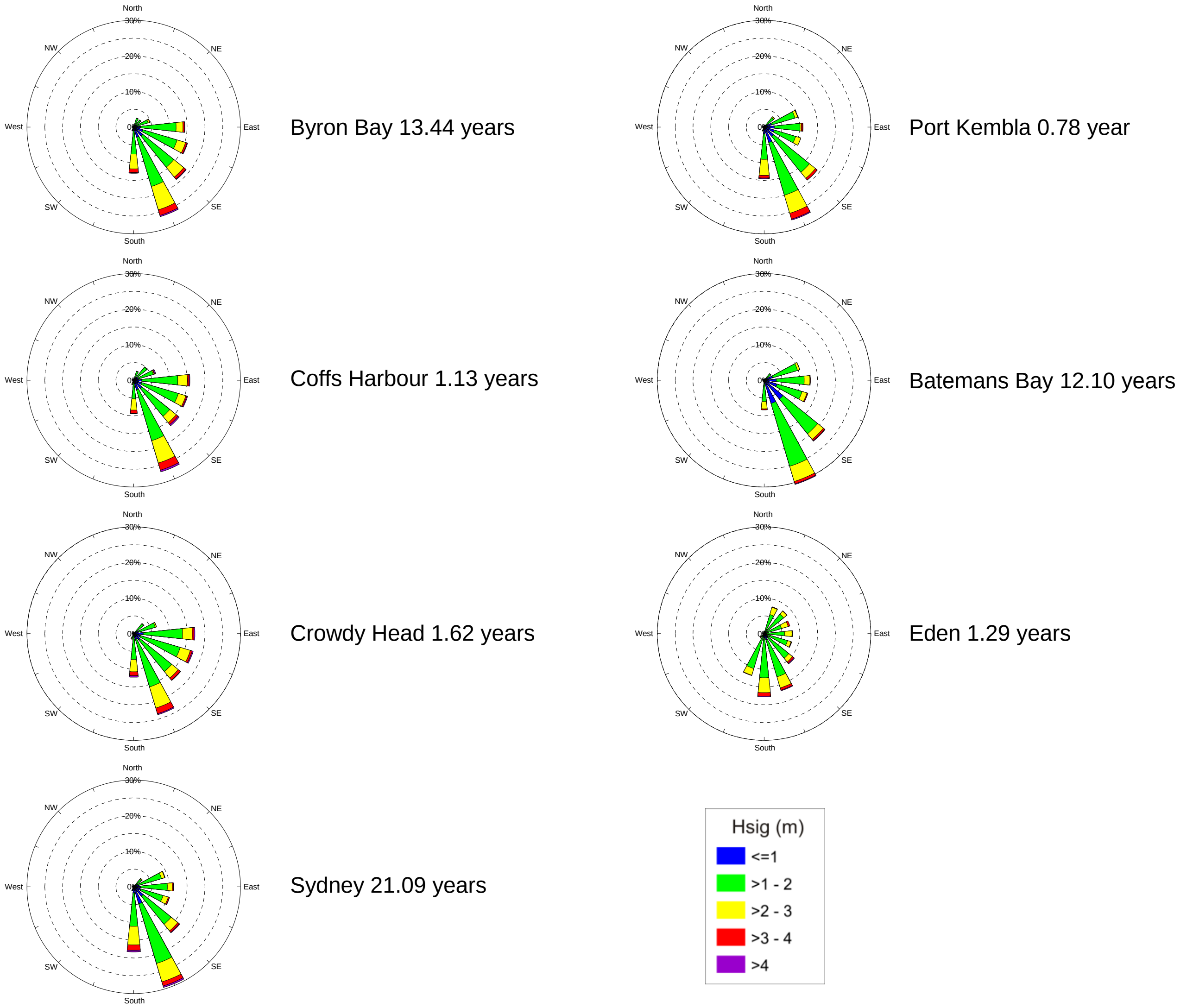

Figure 4 Significant Wave Height and Direction Roses for All Stations to 31 March 2013 – All Data

3.4.2 Seasonal Variations

With over 12 years of hourly wave direction records available for the Byron Bay, Sydney and Batemans Bay stations it is now possible to confidently analyse the three datasets to present a breakdown of the seasonal variation in wave height and direction at each station. It is considered that the shorter records for the recently upgraded directional sites at Coffs Harbour, Crowdy Head, Port Kembla and Eden are not sufficiently long to warrant such analysis at this time. Figure 5 shows the seasonal wave height and direction roses for the three long-term directional stations. The seasons presented are based on the traditional divisions: Summer (December, January and February), Autumn (March, April, May), Winter (June, July, August) and Spring (September, October and November).

The seasonal direction roses for all stations included in Figure 5 clearly display significantly more ENE to ESE wave energy during the summer months than during the rest of the year. This result reflects the anti-cyclone wave generating weather systems and typical NE sea breezes that often dominate for long periods in the Tasman Sea and along the NSW coastline during the summer. During autumn and winter, the directional roses illustrate the progressive swing of the dominant wave direction to the SE to SSE sector and the more frequent higher wave heights at all three stations. This swing of dominant wave energy is associated with the regular development of several types of low pressure systems in the Tasman and southern Tasman Sea during the winter months. The domination of the SE to SSE wave energy weakens during the spring months as the predominant wave energy gradually shifts back towards ENE to ESE that prevails during summer. A summary of the various weather systems that develop in the Tasman and Coral Seas that generate ocean waves along the NSW coast are documented in Shand et al. [5] .

Figure 5 shows that whilst similar seasonal trends are evident at the three stations, wave energy from the south is significantly lower at Batemans Bay. This phenomenon is an artefact of the lower wave climate observed at Batemans Bay due to land mass sheltering and wave generation wind fields discussed in Section 3.2.

3.4.3 Directional Spectra

The rich directional energy data from the Datawell Directional Waverider buoys has provided the opportunity to improve understanding of multi-directional sea states. The directional spectra plot is an ideal method to provide a comprehensive overview of wave conditions in an easily interpreted graphical format. Analysis is performed on board the buoy using Fourier techniques, the data telemetered to MHL then processed and plotted for public access via the internet. A sample of a directional spectra plot for the Port Kembla station is presented in Figure 6 and clearly shows two distinct wave fields. Sea states associated with local high wind events are represented as broad areas of intensifying colour in the edges of the plot as these events generate short period waves with wide directional spreading. Swell that is generated some distance from the buoy are usually shown as small brightly coloured peaks in the plot near the centre as they are associated with long period waves with a narrow spread of direction.

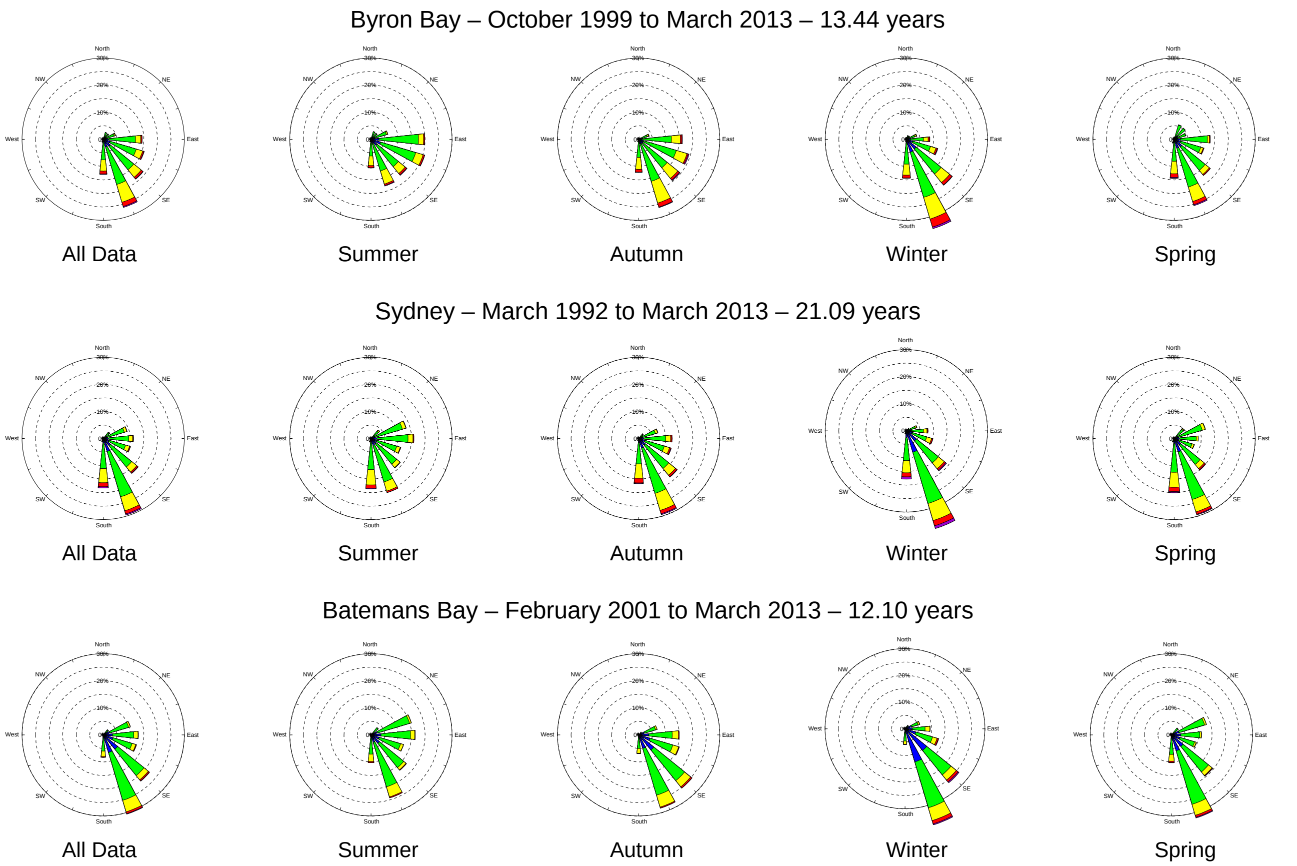

Figure 5 Seasonal Wave Directional Roses for Byron Bay, Sydney and Batemans Bay
(refer to Figure 4 for colour key)

Figure 6 represents a decaying long period ENE swell with a wave period of approximately 10 seconds and a developing southerly swell with a shorter period of 7 seconds.

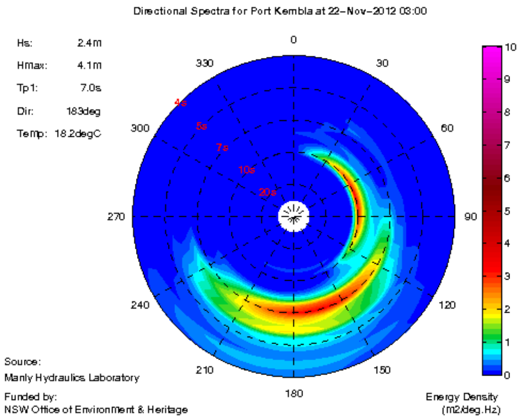

Figure 6 Sample Directional Spectra plot showing two distinct wave direction and energy components

The directional spectra can be used to assess the impact of multi-directional sea states, particularly during storm events. For example, when examining conventional wave time series data graphs, a shorter period swell from the south may mask a longer period swell from the east. Beach erosion or damage to coastal structures at the south end of a beach will easily be explained by the presence of the long period easterly swell in the directional spectra plot. Multi-directional states may also explain the past poor correlation between observed and hindcast information with directional buoy data.

4. The Value of Wave Data

The NSW offshore Waverider buoy network has collected over 220 station years of data since the first station was established in 1974. Four sites now have a record length of over 35 years and directional wave data is available for over 20 years off Sydney. The network therefore represents one of the world's most comprehensive wave datasets and is an irreplaceable asset of the NSW Government. Over the years the data has been extensively used in coastal investigations, design and management. More recently, near real-time data is available to the community via the internet and is utilised by the Bureau of Meteorology in coastal water forecasts, storm warnings and verification of numerical wave models. In recent times, the value of the database as a baseline reference to monitor possible changes in the NSW wave climate due to future climatic change has been realised. Projections of increased storminess, changes to wave direction distributions and the potential impact on coastal processes highlight the need for the continued collection of ocean wave data into the future.

5. Acknowledgements

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6. References

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