FOO Surface Waves Working Group

Review of National Marine Science Plan White Papers for wave observation requirements and current state of wave observations around Australia

Tim Moltmann & Roger Proctor

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1. Introduction

Surface wave observations are needed to inform a wide range of ocean, shelf and coastal activities and to aid wave model development. Australia currently has a wave buoy network, reporting in real-time, and many historical observations.

Because of its scale and geographical location Australia experiences many wave environments and phenomena which a wave buoy network needs to be able to resolve and capture whilst at the same time being affordable and sustainable. The US have recognised that changing times will impact on the design and cost of a wave buoy network. In 2009 the paper 'A National Operational Wave Observation Plan' proposed a network, that when completed, would include a total of 296 sensors: 56 in the Offshore, 60 Outer-Shelf, 47 Inner-Shelf, and 133 Coastal. Of these, 115 would be new and directional upgrades would be required at 128 locations. By 2012 this plan had been revised, 'IOOS Wave Observations, a National Perspective' to focus on the existing 200 locations, and defined a perimeter 'Backbone' network of observing sites and proposed adding 47 new locations and upgrading the directional wave measurement of 87 stations. In addition 10 'Rover Buoys' were recommended to be used with one year deployments to evaluate regional wave models so that they (the models) can be used as virtual wave gauges. The plan also identified 60 of the existing US backbone locations with record lengths of 20 years or longer ("Sentinel Stations") as critical to understanding climatic changes to the Nation's wave conditions. In addition the paper reviewed the process of using wave models and short-term wave sensor deployments to optimize the wave observations in a particular region. This plan was recommended for another revision in the 2017 paper 'National Strategy for a Sustained Network of Coastal Mooorings'; this review has yet to appear.

Of the 7 societal benefits of the US-IOOS (Ocean.US, 2006) the 2009 plan noted waves were specifically important to:

- Predict climate change and weather and their effects
- Conduct safe and efficient marine navigation
- Mitigate the effects of natural hazards
- Ensure national and homeland security
- Reduce public health risks.

The purpose of this white paper is to step back and review the current Australian wave buoy network, the availability of wave observations, and their quality, and to consider whether or not the status meets the national needs. These needs have been articulated (to some exent) in the white papers prepared as background material for the National Marine Science Plan 2015-2025 and the papers are used as the starting point for the assessment.

2. Review of NMSP White Papers

In preparation for developing the 10-year National Marine Science Plan the marine community was invited to submit 10-page White Papers addressing the 7 themes to be presented in the plan:

- Sovereignty, security and natural hazards
- Energy security
- Food security
- Biodiversity conservation and ecosystem health
- Dealing with climate change
- Optimal resource allocation
- Urban coastal environments

plus an underpinning White Paper on Infrastructure (see here). White papers needed to address issues related to relevance, science needs, perspective and realisation.

Wave observations figure in three of these white papers **– Energy Security**, **Dealing with Climate Variability and Change**, and **Sovereignty, Security and Natural Hazards**. The main points raised in these white papers, extracted below, can be considered in 3 groupings a) present data availability, b) use by stakeholders, and c) value for forecasting and climate prediction.

a) Present data availability
    - existing marine infrastructure is inconsistent with the size of Australia's marine estate
    - wave monitoring is mostly undertaken by state authorities and coverage is patchy. Some observations record wave height and period but not direction.
    - in some regions, e.g. NW Shelf, waves may be measured by industry but the data is not readily available to the community
    - a nationally coordinated wave observation dataset is imperative
    - data processing and archiving is inconsistent between data custodians, which may limit the application of the data for determining long-term variability
    - centralised management and access to marine environmental data will provide benefits to the offshore industries and the Australian Government and improve the management of risk
    - centralisation of operation of ongoing observations may broaden their utility
    - extremes of sea level (combined tides, surges, waves) are a particular concern for many communities. Understanding historical variability of wave climate extremes is severely limited by an inadequate national wave observing network
    - there should be a strategy to develop environmental baselines fundamental reference conditions.

b) Use by stakeholders
    - there are increasing global societal demands for low carbon energy sources, and wave power is an option; the potential for wave power in Australia's vast estate is only beginning to be evaluated
    - there is a pressing need to develop a nationally-consistent and comprehensive marine environmental baseline (e.g. wave climate information) for Australia's marine estate particularly adjacent to existing and developing energy sinks (ports, cities) to reduce uncertainty for future developments

- economically, provision of pre-competitive marine data should attract industry to explore this resource
- companies need easy access to marine data to provide greater certainty for operating in the marine environment
- wave parameters and their changes due to changing climate are of interest to a wide range of stakeholders
- in the absence of reliable long-term monitoring, coastal and offshore infrastructure will continue to be conservatively designed incurring unwarranted expenditure.

c) Value for forecasting and climate prediction
   - there is a paucity of real time data in most areas
   - reliable assessments of present climate risk and trends in these risks are hindered by the sparsity in space and time of current observational wave records
   - the needs for near-shore wave measurements include climate studies, operational activities and engineering design
   - in a changing climate, ongoing monitoring is fundamental to determining whether and when expensive adaptation of coastal infrastructure becomes necessary
   - wave observations are critical for validation of operational wave models, and for demonstrating skill to enable confidence in climate forecasts and hindcasts
   - waves are an important contributor to, and have a strong influence on, the flux of constituents through the air-sea interface.

Overall, these can be summarised as

a) wave observations are inhomogeneous in space, time, and quality
b) many stakeholders utilise wave observations and access (to them) and analysis (baselines) offers economic benefits; there is a need for a centralised repository
c) forecast models need validating with observations for forecasts to be credible; real time forecasting suffers from a lack of real-time observations.

An example of a stakeholder group with interest in waves, given in the table below, is the ocean renewable energy industry, as given in the ARENA report ("A Revised Assessment of Australia's National Wave Energy Resource", 2017, Hemer, Zieger, Durrant, O'Grady, Hoeke, McInnes & Rosebrock, Renewable Energy, 114, 85-107. http://dx.doi.org/10.1016/j.renene.2016.08.039).

Stakeholder Group	**Purpose/Interest**
Developers of wave energy converter devices	Require knowledge to enable optimisation of a device for available resource
Project prospectors	Seeking commercially viable projects
Marine spatial planners	Seeking to incorporate resource knowledge into multiple-use management and policies for the marine domain
Environmental managers	Seeking benchmark information for pre-deployment environmental conditions
Financiers	Seeking independent information to assess whether projects are bankable, allowing developers to access capital
Energy load managers	For assessment of potential power delivery/integration to user/electricity network, to negotiate reliable power purchase, and investigate other grid integration issues.
Maintenance engineers	To determine engineering installation, operations and maintenance requirements.

3. Current publically available in situ wave network

National Operational Wave network

Table 1 provides details of the 'in principle' publically available network, i.e. data is freely available if you contact the owner (or can download in some cases). It consists of 36 stations around the coast, which are shown geographically in Fig. 1. It is worth noting that Table 1 is not a comprehensive list of all current buoys with data that is publically available.

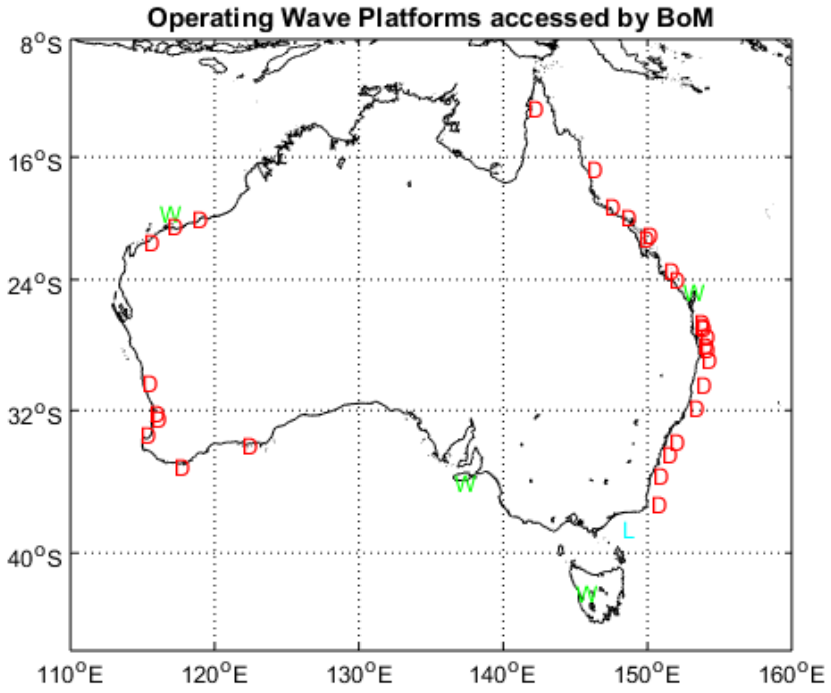


Fig. 1. Locations of wave buoys in the National buoy network (D=directional, W=waverider, L=laser)

Most available offshore observations described here are (have been) collected using Datawell Waverider buoys (http://www.datawell.nl/Products/Buoys.aspx), either with no directional capability (mostly older observations but not all) or with directional capability (newer deployments). A subset of these data are used for ongoing validation of the Bureau of Meteorology's operational wave model forecasts.

Table 1 Details of wave observing platforms in the National buoy network. Acronyms in the 'Owner' Column are as follows: QLD DSITI: Queensland Department of Science, Information Technology and Innovation; ESSO: Esso Pty Ltd.; OEH/MHL: New South Wales Office of Environment and Heritage/Manly Hydraulics Laboratory; BoM: Bureau of Meteorology; WA DOT: Western Australia Department of Transport; PPA: Pilbara Ports Authority; WOOD: Woodside Pty Ltd.

Date Deployed	Date Directional	Name	Lat	Lon	Depth	Type	Owner
22/12/1978	25/11/2008	Albatross Bay	-12.68	141.68	10	Directional Waverider	QLD DSITI
04/05/1975	26/02/2016	Cairns	-16.73	145.72	15	Directional Waverider	QLD DSITI
20/11/1975	29/10/2008	Townsville	-19.17	147.05	18	Directional Waverider	QLD DSITI

17/01/2012	17/01/2012	Abbot Point	-19.87	148.1	14	Directional Waverider	QLD DSITI
19/09/1975	13/03/2002	Mackay	-21.03	149.55	29	Directional Waverider	QLD DSITI
24/04/1977	31/10/2009	Hay Point	-21.27	149.31	10	Directional Waverider	QLD DSITI
24/07/1996	24/07/1996	Emu Park	-23.3	151.07	22	Directional Waverider	QLD DSITI
23/09/2009	23/09/2009	Gladstone	-23.9	151.5	13	Directional Waverider	QLD DSITI
8/09/2015	n/a	Bundaberg	-24.67	152.5	18	Waverider	QLD DSITI
20/04/2000	11/05/2005	Mooloolaba	-26.57	153.18	32	Directional Waverider	QLD DSITI
1/05/2013	01/05/2013	Caloundra	-26.85	153.16	12	Directional Waverider	QLD DSITI
08/03/2010	08/03/2010	North Moreton	-26.9	153.28	35	Directional Waverider	QLD DSITI
31/10/1976	20/01/1997	Brisbane	-27.5	153.63	73	Directional Waverider	QLD DSITI
21/03/1987	17/07/2007	Gold Coast	-27.97	153.44	18	Directional Waverider	QLD DSITI
6/06/2017	6/06/2017	Tweed Heads	-28.18	153.58	25	Directional Waverider	QLD DSITI
14/10/1976	26/10/1999	Byron Bay	-28.87	153.69	62	Directional Waverider	OEH/MHL
26/5/1976	19/8/2011	Coffs Harbour	-30.36	153.27	72	Directional Waverider	OEH/MHL
10/10/1985	19/08/2011	Crowdy Head	-31.81	152.86	79	Directional Waverider	OEH/MHL
3/3/1992	3/3/1992	Sydney	-33.77	151.41	92	Directional Waverider	OEH/MHL
7/2/1974	20/06/2012	Port Kembla	-34.47	151.02	80	Directional Waverider	OEH/MHL
27/5/1986	23/02/2001	Batemans Bay	-35.71	150.34	62	Directional Waverider	OEH/MHL
8/2/1978	16/12/2011	Eden	-37.26	150.19	100	Directional Waverider	OEH/MHL
23/07/2008	n/a	Kingfish B	-38.6	148.19	78	Laser Wave Gauge	ESSO
2/01/1998	n/a	Strahan	-42.08	145.01	100	Waverider	BOM
1/11/2000	n/a	Cape Du Couedic	-36.07	136.62	80	Waverider	BOM
18/06/2006	1/01/2012	Esperance	-34	121.9	52	Directional Waverider	WA DOT
26/07/2005	3/09/2008	Albany	-35.2	117.17	60	Directional Waverider	WA DOT
28/05/1999	11/02/2010	Cape Naturaliste	-33.36	114.78	50	Directional Waverider	WA DOT
12/06/2014	12/06/2014	Mandurah	-32.45	115.57	30	Directional Waverider	WA DOT
11/03/1994	14/09/2004	Rottnest Island	-32.11	115.4	48	Directional Waverider	WA DOT
01/01/1998	27/10/2009	Jurien Bay	-30.29	114.91	42	Directional Waverider	WA DOT
04/09/1999	14/02/2008	Cottesloe	-31.98	115.69	27	Directional Waverider	WA DoT
25/06/2016	25/06/2016	Ashburton	-21.54	115.03	11	Directional Waverider	PPA

8/12/2015	8/12/2015	Dampier	-20.44	116.73	15	Directional Waverider	PPA
10/12/2015	10/12/2015	Port Hedland	-20.01	118.44	17	Directional Waverider	PPA
6/09/2000	n/a	North Rankin	-19.59	116.14	125	Waverider	WOOD

Of these stations 30 are operated by State or Federal authorities and five are commercially operated (Kingfish B (Esso), North Rankin (Woodside) and Ashburton, Dampier, Port Hedland (Pilbara Ports Authority). It should be noted that wave stations denoted 'D' (Directional Waverider buoys) have not had directional capability since deployment, most started out without directional capability, and have subsequently been upgraded (see Table).

Wave direction is an important parameter and without it the wave measurements are less valuable. In the operational network buoy upgrades have resulted in 32 of the 35 buoys having directional capability; however, most of those with directional capability have been installed for less than 10 years. The distribution, shown in Fig. 1, indicates there are still gaps in the operational network, especially the northwest shelf and the Great Australian Bight, and it should be noted that there are no directional measurements between Esperance (WA) and Eden (NSW).

Greenslade et al (Greenslade, D., Zanca, A., Hemer. M, and S. Zieger, Optimising the Australian Wave Observation Network, submitted to J. S. Hem. Earth Sys. Sci.) analysed spatial correlations of monthly mean values of Hs, Tp and mean direction from the CAWCR hindcast (http://doi.org/10.4225/08/523168703DCC5, https://doi.org/10.4225/08/52817E2858340, http://doi.org/10.4225/08/55C99193B3A63) spanning 1979-present (see Section 6) with the aim of identifying how well the existing National buoy network can observe the spatial variability in the wave climate. An example of the results for Hs is shown in Fig. Red areas represent those areas where the wave climate is well resolved by the existing network, and orange/white areas where the wave climate is less well-resolved.

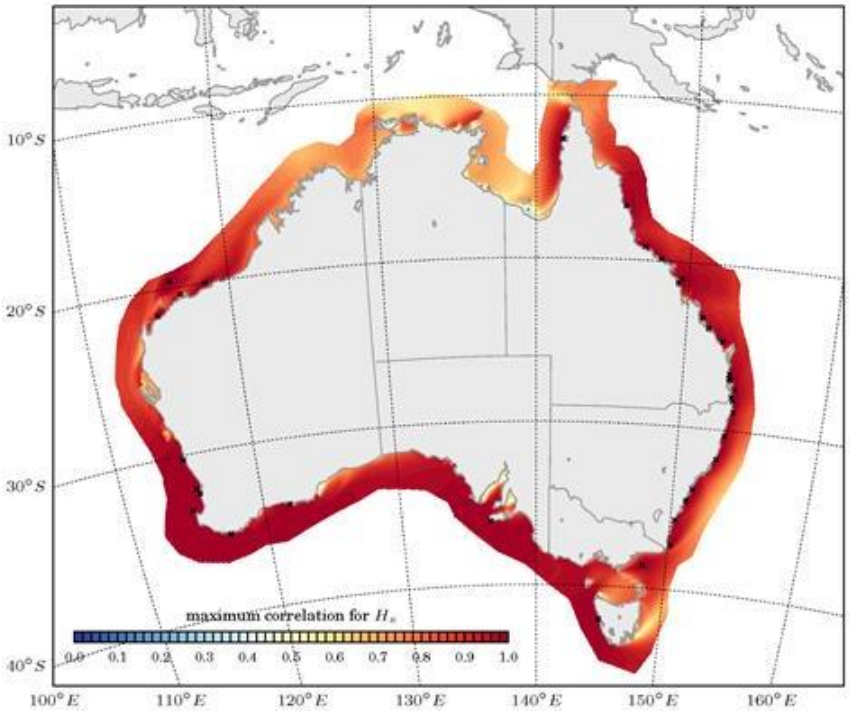


Fig. 2 Maximum correlations between monthly mean Hs at each grid point and monthly mean Hs at each buoy site within the publically available network

It is worth noting that the depth of buoy sites are almost all in 'intermediate' depths, and proximal to coasts. This has some important implications in that by being in intermediate depths, the measured waves are only representative of the location they are deployed. If deployed in deep water (Depth > ½ wavelength) then the wave hasn't undergone any transformation and is representative of larger area. In intermediate depths, the measured wave is dependent on the upwave bathymetry. Being proximal to coasts has implications that they have limited use for calibration of satellite measured waves but on the other hand, they are more relevant for local users, e.g. ports.

State wave observations around Australia, real-time and historical

Western Australia, http://www.transport.wa.gov.au/imarine/about-wave-data.asp

Real-time wave recorders in WA operated by Department of Transport are shown in Fig. 3.

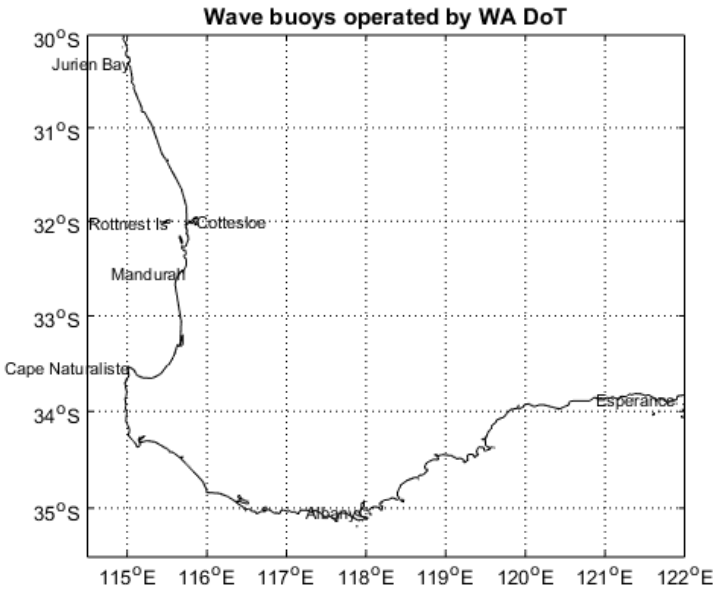


Fig.3 WA DoT real-time wave recorders

Latest recordings for the real-time stations are given by these links

- Albany tide and wave.
- Cape Naturaliste tide and wave.
- Cottesloe tide and wave.
- Esperance tide and wave.
- Jurien Bay tide and wave.
- Mandurah tide and wave.
- Rottnest Island tide and wave

Historical wave records are accessible at http://www.transport.wa.gov.au/imarine/historical-tide-and-wave-data.asp. Full list of data holdings is given in Appendix-1.

DoT have developed a Google Earth UI for all their wave data. These data can be obtained via a KMZ file (e.g. WaveStations_20160620.kmz, Ralph Talbot-Smith, Ralph.Talbot-Smith@transport.wa.gov.au). Fig. 4 below shows an example lay out of stations; clicking on a particular station, for example Jurien Bay, provides access to station details.

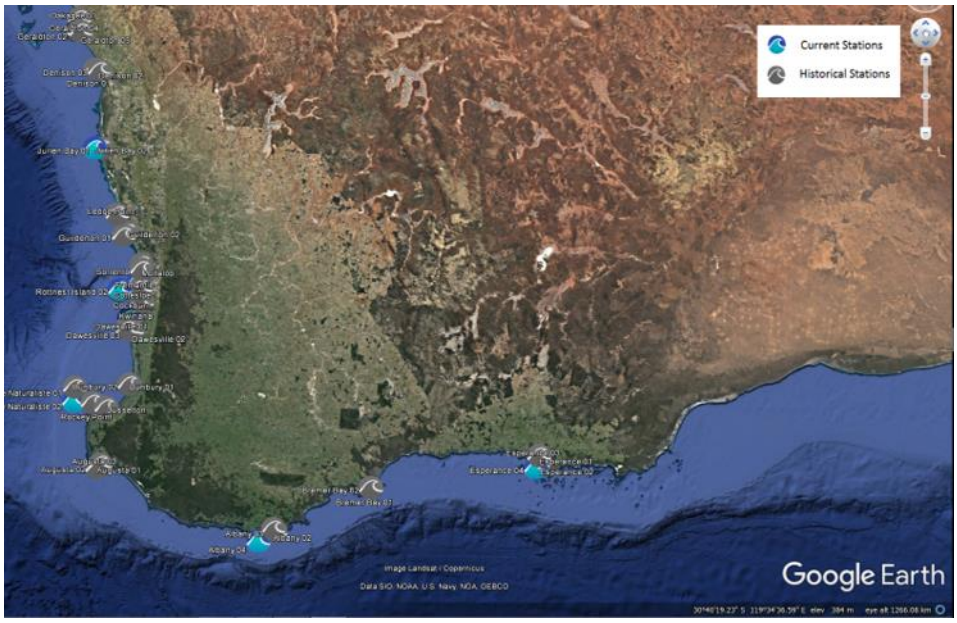
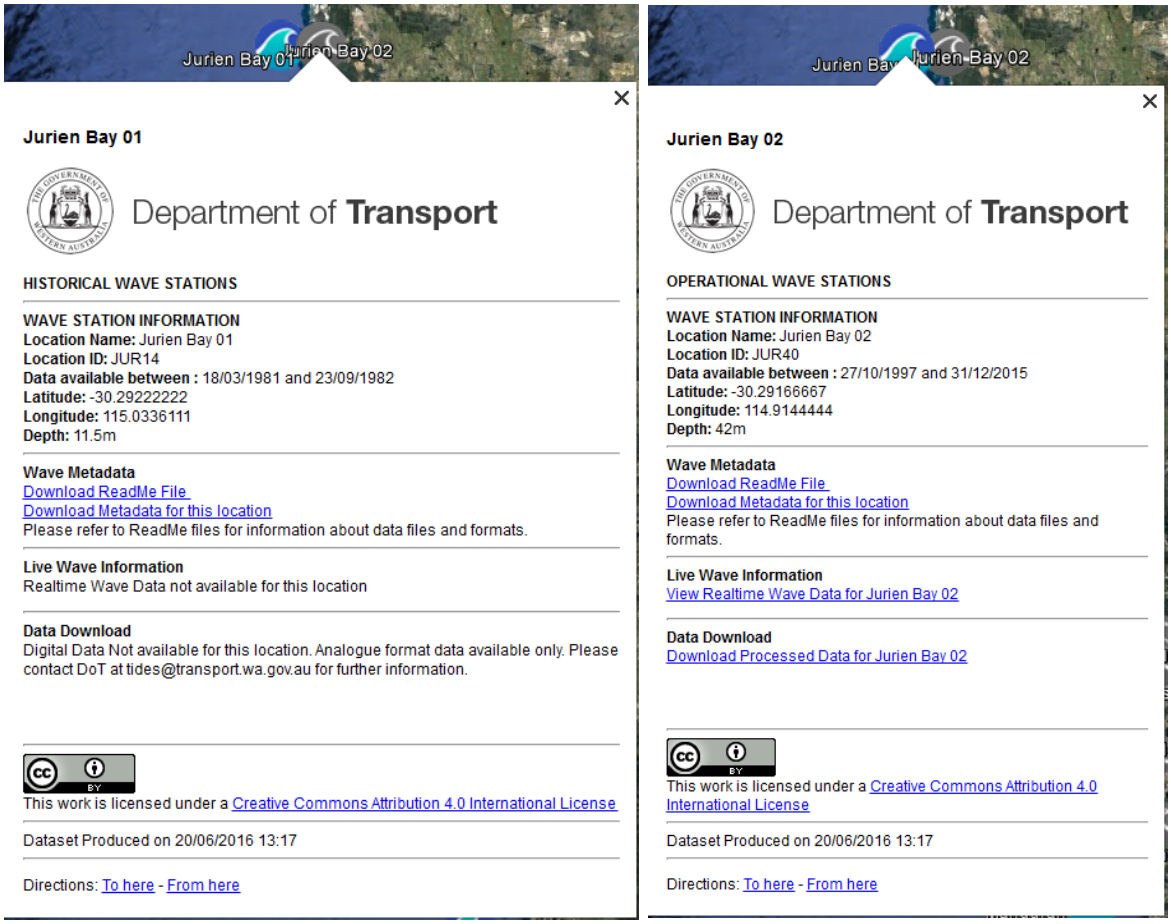


Fig. 4 Google Earth UI for WA wave stations

Example information for Jurien Bay deployments shown below, indicating both historical and operational wave data collections.



Queensland, https://www.qld.gov.au/environment/coasts-waterways/beach/waves-sites/

Real-time wave recorders operated by QLD State Government are shown in Fig. 5.

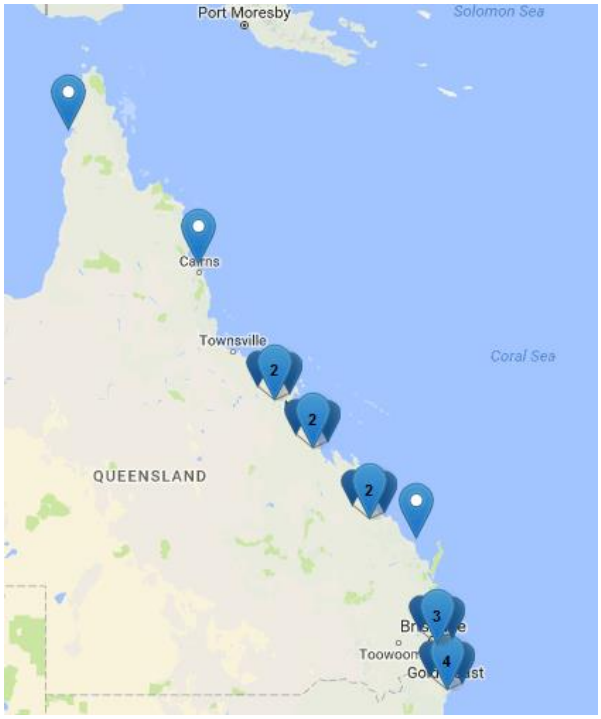


Fig. 5 Real-time wave monitoring sites in QLD

The latest wave heights, wave direction (except at Bundaberg) and sea surface temperature are available through the following links, which also give some station information.

Far North Queensland

- Cairns, Albatross Bay (Weipa)

North Queensland

- Abbot Point, Townsville

Mackay and Fitzroy Central

- Bundaberg, Gladstone, Emu Park, Hay Point, Mackay

South East Queensland

- Tweed Heads, Palm Beach, Gold Coast, Brisbane, North Moreton Bay, Caloundra, Mooloolaba

Real-time station details are given in Appendix-2; historical station details are given in Appendix-3.

New South Wales, Manly Hydraulics Laboratory collects wave data under the NSW Coastal Data Network Program managed by the Office of Environment and Heritage (OEH), for details see http://www.mhl.nsw.gov.au/data/realtime/wave/.

Since 1974 wave data have been collected at over 40 locations along the NSW coast using a variety of wave motion sensors. Operating real-time offshore wave recorders are indicated in Fig. 6.

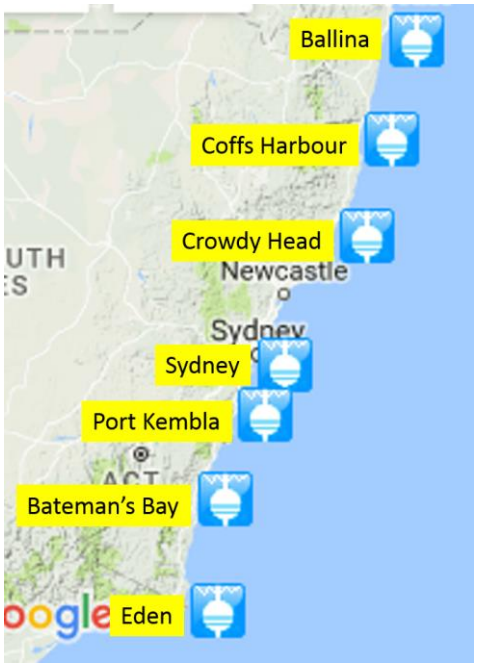


Fig. 6 NSW real-time wave stations

Details of deployments are given below in Table 2. The buoys are typically moored in water depths between 60 and 100 metres between 6 and 12 kilometres from the shoreline.

Table 2 NSW Offshore Waverider Buoy Stations

Wave Data Site	Instrument	Location		Water Depth (m)	Data Available	
		Latitude (E)	**Longitude (S)**		**First Date**	**Last Date**
Byron Bay	Waverider buoy	28° 43' 32"	153° 44' 40"	72	14-Oct-1976	26-Oct-1999
Byron Bay	Directional Waverider	28° 52' 14"	153° 41' 39"	62	26-Oct-1999	Present
Coffs Harbour	Waverider buoy	30° 21' 41"	153° 16' 11"	72	26-May-1976	13-Feb-2012
Coffs Harbour	Directional Waverider	30° 21' 45"	153° 16' 09"	72	14-Feb-2012	Present
Crowdy Head	Waverider buoy	31° 49' 31"	152° 51' 35"	79	10-Oct-1985	19-Aug-2011
Crowdy Head	Directional Waverider	31° 48' 50"	152° 51' 22"	79	19-Aug-2011	Present
Sydney	Waverider buoy	33° 46' 45"	151° 25' 05"	85	17-Jul-1987	04-Oct-2000
Sydney Directional	Directional Waverider	33° 46' 18"	151° 24' 31"	90	03-Mar-1992	Present
Port Kembla	Waverider buoy	34° 28' 28"	151° 01' 34"	80	07-Feb-1974	14-May-2012
Port Kembla	Directional Waverider	34° 28' 19"	151° 01' 18"	80	20-Jun-2012	Present
Batemans Bay	Waverider buoy	35° 42' 34"	150° 20' 41"	73	27-May-1986	23-Feb-2001
Batemans Bay	Directional Waverider	35° 42' 11"	150° 20' 38"	73	23-Feb-2001	Present
Eden	Waverider buoy	37° 18' 06"	150° 11' 06"	100	08-Feb-1978	16-Dec-2011
Eden	Directional Waverider	37° 15' 57"	150° 11' 36"	100	16-Dec-2011	Present

Data are available upon request, http://new.mhl.nsw.gov.au/DataRequests.

Some of the Offshore Waverider data (to 31 December 2015) is already available through the AODN, see https://portal.aodn.org.au or as netCDF files at http://imos-data.s3-website-ap-southeast-2.amazonaws.com/?prefix=NSW-OEH/Manly_Hydraulics_Laboratory/Wave/.

In addition to the operation of offshore Waverider buoy network, MHL undertakes site specific wave data capture programs associated with particular projects, such as breakwater design/construction,

harbour design/construction, beach erosion investigations, etc. The wave characteristics at these inshore locations may be significantly affected by refraction, diffraction, shoaling and friction attenuation. Appendix – 4 provides a list of inshore wave data collection sites operated by MHL.

Victoria

The state has recognised that filling wave monitoring gaps along the Victorian coast would be valuable as part of a National backbone whilst meeting regional needs. The Department of Environment, Land, Water and Planning are interested (Daniel Ierodiaconou, Deakin University, pers. comm.) in investing in infrastructure to fill the gap in Victorian coastal waters and have ~$700,000 to invest at this point in time and are looking at co-investment/ collaborative opportunities for data sharing, delivery and maintenance for sustained monitoring.

Other wave buoy operators

Bureau of Meteorology

The Bureau operate two waverider buoys (non-directional)

- Cape du Couedic Wave Observations, located at 36.07S, 136.62E (4nm West of Cape du Couedic Light House, Kangaroo Island), http://www.bom.gov.au/products/IDS65030.shtml
- Cape Sorell Waverider Buoy Observations, located at 42.12S, 145.03E (Approximately 10 Km West of Cape Sorell, West Tasmania), http://www.bom.gov.au/products/IDT65014.shtml

AODN has these wave data: Cape Couedic 2000-2012, and Cape Sorrell 1998-2012.

Privately owned wave buoy operators

Offshore and port operators have, for many years, monitored surface waves at various one-off, repeat and/or continuous locations.

RPS MetOcean: Greg Williams (Greg.Williams@rpsgroup.com.au) has provided information about deployments. Fig. 7 shows locations of QC'ed datasets, some running back 30-40 years.

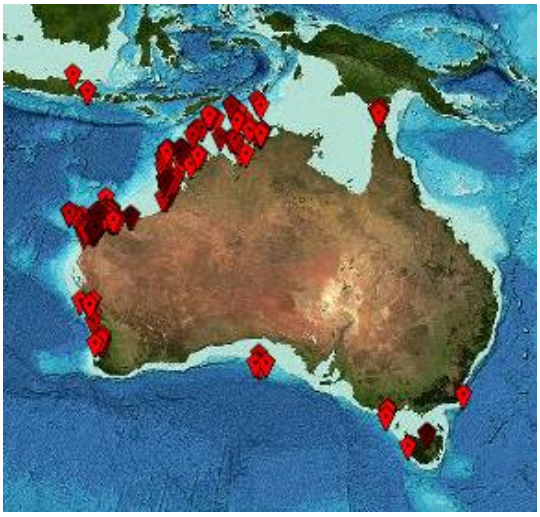


Fig. 7. RPS MetOcean locations of QC'd wave and wind observations

(excludes 800+ sites in the Gulf of Carpentaria/Mornington, the GAB and Bass Strait)

Some deployments contain a 'continuous' (permanent) measurement programme across 25 years (eg. North Rankin has 25 years of data), others are 'seasonal' (eg. cyclone moorings/measurements span decades but only Oct-May), and the rest are 'transient' measurement programmes (minimum 6 months, but usually 1-2 years). Anything in the 'QC' database has been collected by carefully calibrated instruments (rechecked/reset every 3-6 months) and meticulously reviewed and quality-controlled by oceanographers (ie. very different from just 'raw' obs data).

A snap shot of real-time feeds from April 2016 is shown below, Fig. 8.

Fig. 8. RPS MetOcean real-time stations

Cardno: Daniel Strickland (daniel.strickland@cardno.com.au) writes … regarding our wave buoy operations in Western Australia: Currently Cardno facilitates maintenance and real-time data feed for a DWR-G buoy for Rio Tinto – Dampier Salt Ltd at Cape Cuvier. This buoy has been in place for over 5 years. This data has not been and isn't in the public domain. BoM have been keen to access this data for a while and Rio Tinto have not been averse to providing, but they have not been very active in pushing this. We have offered to help them facilitate this a few times over the past 5-6 years. That being said, they have informed me they are in contact with BoM at the moment to try to get this happening soon. Cardno also deployed a directional waverider buoy (MkII I believe) offshore of Alkimos (North Perth, WA) from November 2009 to June 2010, to assist with construction of a wastewater pipeline. I believe this data is in an SQL database somewhere and is probably not publically accessible.

Chevron: Aaron Miragliotta (Aaron.Miragliotta@chevron.com) writes … As far as I know, the data from the WRB located at Barrow Island in Western Australia isn't posted on the public domain, though there was an effort last year sometime to share the same data with the BoM, I don't know where that left off, I will try to find out who owns the contract, but I suspect the information sharing will be private. Chevron uses the WRB to support operationally based decision making with respect to pilotage of ships using the Gorgon marine terminal in Western Australia, here operations are pretty much looking for unfavourable wave, swell and wind conditions that might impact transit of the channel, i.e. wave periods of >4s or 6s are the area of focus even though the Datawell WRB can measure below this period.

Port Authority NSW: Andrew Tsaccounis (ATsaccounis@portauthoritynsw.com.au) writes … Below, Table 3, is a summary of the current Waverider buoys we have deployed.

Table 3. Details of NSW Ports wave buoys.

Location	Latitude	Longitude	Start Date	End Date	Sensor Type
Offshore, Botany Bay	-34°02'28.3	151°15'12.1"	1998	Currently recording	0.9m MKIII DWR, Cunifer*
Captain Cook, Botany Bay	-33°59'53.4"	151°12'32.9"	2016	Currently recording	0.9m SG, Cunifer*
Kurnell Botany Bay	-33°59'33.1"	151°13'18.4"	1998	Currently recording	0.7m SG, Cunifer*
Brighton Botany Bay	-33°58'53.3"	151°10'15.2"	2003	Currently recording	0.9m MKIII DWR, SS*
Bombora Botany Bay	-33°59'41.6"	151°13'41.7"	2009	Currently recording	0.9m MKIII DWR, Cunifer*
Muganno Point TwoFold Bay	-37°06'15.0"	149°55'31.0"	2015	Currently recording	0.9m FL. SS*
Inner Newcastle	-32°54'57.0"	151°48'33.0"		Currently recording	0.9m MKIII DWR, SS*
Outer Newcastle	-32°54'57.0"	151°48'45.0"		Currently recording	0.9m MKIII DWR, SS*
Kooragang					

*refers to the casing composition, SS=stainless Steel.

These buoys are used as an aid to shipping and pilotage within their respective ports. All our Sydney and Eden sensors are displayed on our external webpage http://wavewindtide.portauthoritynsw.com.au/ . Data is available by paid subscription to all our devices. We don't hand out our data for free as we are a self-funded corporation.

Other wave measurements

The Integrated Marine Observing System (IMOS, www.imos.org.au) operates two facilities which are (or have been) measuring waves: 1) the National Mooring Network and 2) the Coastal Radar Network. These data are described in Table 4.

Table 4. IMOS wave data collections

Moorings

Location	Latitude	Longitude	Start Date	End Date	Sensor Type
Beagle Gulf	-12.1079	130.5879	Jan 7, 2014 Sep 14, 2014	Apr 24, 2014 Ongoing	RDI ADCP - WORKHORSE SENTINEL NEMO
Darwin	-12.3381	130.6965	Aug 14, 2009 Jan 1, 2011	Sep 26, 2009 Ongoing	NORTEK ADCP - AWAC with NIP RDI ADCP - WORKHORSE

					SENTINEL NEMO
Yongala	-19.3016	147.6200	Apr 13, 2011	Ongoing	RDI ADCP - WORKHORSE SENTINEL NEMO
One Tree Island	-23.4832	152.1727	Apr 8, 2014 Oct 5, 2016	Apr 4, 2016 Ongoing	NORTEK ADCP - AWAC AST
Heron Island	-23.5133	151.9550	Sep 25, 2012	Mar 23, 2013	NORTEK ADCP - AWAC
Maria Island	-42.589184	148.23349	Dec 7, 2015	May 19, 2017	Microstrain 3DM-GX1
North Stradbroke Island	-27.3414	153.56197	Feb 3, 2016	May 22, 2017	Microstrain 3DM-GX1
SOTS SOFS	-46.6665 -46.7771 -46.6665	142.0732 141.9931 142.0732	Nov 21, 2011 Apr 19, 2013 Mar 24, 2015	Jul 30, 2012 Oct 31, 2013 Apr 13, 2016	TriAXYS OEM wave sensor

Mooring data available at http://thredds.aodn.org.au/thredds/catalog/IMOS/ANMN/catalog.html, SOTS data at http://thredds.aodn.org.au/thredds/catalog/IMOS/ABOS/catalog.html.

Coastal Radar Sites

Location	Latitude	Longitude	Start Date	End Date	Sensor Type
South Australian Gulfs Stations: Cape Wiles (CWI), Cape Spencer (CSP)	min: -37.4552 max: -34.8234	min: 132.9540 max: 137.4627	Dec 2, 2009	Ongoing	WERA Oceanographic HF Radar
Rottnest Shelf Stations: Fremantle (FRE), Guilderton (GUI)	min: -33.4338 max: -30.1507	min: 113.1520 max: 115.7412	Jan 1, 2010	Ongoing	WERA Oceanographic HF Radar
Coffs Harbour Stations: Red Rock (RRK), North Nambucca (NNB)	min: -31.6096 max: -29.3635	min: 153.010561 max: 154.775963	Dec 27, 2012	Ongoing	WERA Oceanographic HF Radar
Capricorn Bunker Group Stations: Tannum	min: -24.1958 max: -21.9203	min: 150.7817 max: 153.5534	Aug 1, 2009	Apr 7, 2017	WERA Oceanographic HF Radar

Sands (TAN), Lady Elliot Island(LEI)					

Individual stations give wave height, combined stations give wave height and direction. Radar data available at http://thredds.aodn.org.au/thredds/catalog/IMOS/ACORN/gridded_1h-avg-wave-site-map_QC/catalog.html.

The radar wave measurements at the South Australian Gulfs Site (Stations Cape Wiles (CWI) and Cape Spencer (CSP)) offer the only directional wave data between Esperance (WA) and Eden (NSW).

Wave Gliders

The Australian Institute of Marine Science (AIMS) in partnership with Boeing, has recently completed a seven-day trial of a Wave Glider, developed by Boeing subsidiary Liquid Robotics (https://www.liquid-robotics.com/). The trial saw the vehicle, powered by waves and sun, cover 200 nautical miles of the central Great Barrier Reef, and demonstrated how a high-tech autonomous ocean vehicle can improve monitoring of the Great Barrier Reef and coastal waters. AIMS head of Data and Technology Innovation Lyndon Llewellyn said researchers were still analysing data captured by the high-tech vehicle and were impressed with the number of different measurements it could conduct at the same time and its ability to transmit the data back to base immediately and reliably.

https://www.aims.gov.au/docs/media/latest-releases/-/asset_publisher/8Kfw/content/autonomous-technology-helps-scientists-put-eyes-on-great-barrier-reef

An example of the use of historical wave observations in developing wave climatologies

A good starting point for assessing the Australian wave data holdings is the Arena report (Hemer et al, 2017) which undertakes a comprehensive verification of the 34-year (1979-2014) CAWCR wave model hindcast (http://doi.org/10.4225/08/523168703DCC5) used to produce the Australian Wave Energy Atlas (http://awavea.csiro.au/).

The validation of the hindcast was conducted against wave observations at in-situ sites with locations shown in Fig. 9 and listed in Table 5. No information is given regarding quality of data available.

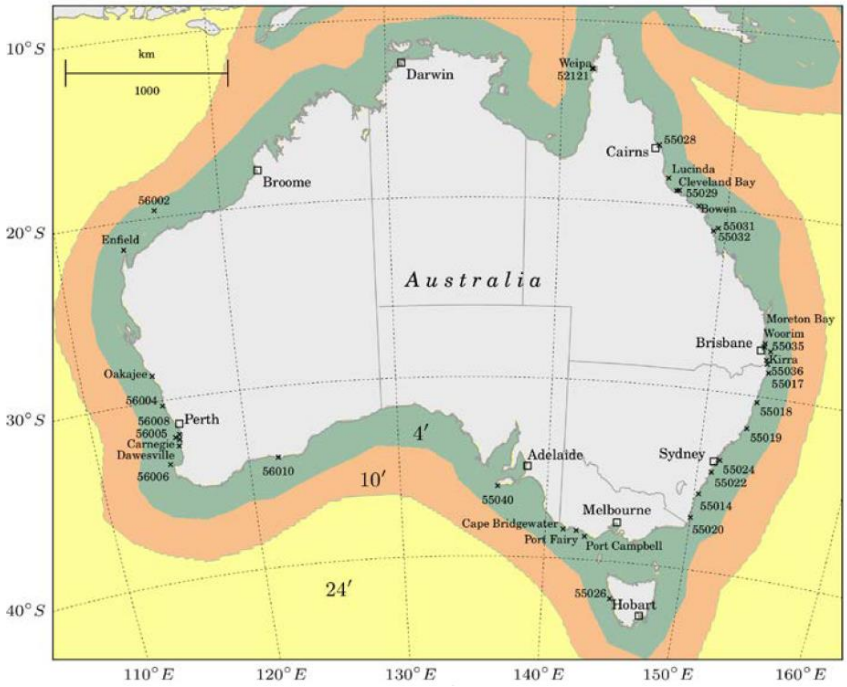


Fig 9. Map of Australia showing the location of selected buoys used to verify the Australian grid. The exact position of locations is listed in Table 2. Shades of colour show the model grid resolutions used in the 35-year CAWCR hindcast. High-resolution coastal grids are nested within a 24' (~44km) global grid (yellow). Colour shades show regions of increasing resolution of 10' (~18km; orange) and 4' (~7km; green), respectively. From Hemer et al (2017), Figure 2.

Table 5. List of buoy station used for validation. Buoys are identified by their WMO number (where assigned) otherwise by station name. Asterisk denotes directional waverider buoys. Buoys are often moved during longer deployments, see appendices.

WMO no./ Station name	Buoy depth	Longitude °W	Latitude °N	Data provider	Time period
52121*	10 m	141.68	-12.69	QLD	2008/11 - 2013/12
55014	73 m	150.32	-35.76	NSW Manly Hydraulics	1986/05 - 2010/12
55017	62 m	153.69	-28.64	NSW Manly Hydraulics	1976/10 - 2010/12
55018	72 m	153.24	-30.34	NSW Manly Hydraulics	1976/05 - 2010/12
55019	79 m	152.85	-31.83	NSW Manly Hydraulics	1985/10 - 2010/12
55020	100 m	150.00	-37.11	NSW Manly Hydraulics	1978/02 - 2010/12
55022	80 m	150.96	-34.48	NSW Manly Hydraulics	1974/02 - 2010/12
55024	92 m	151.40	-33.77	NSW Manly Hydraulics	1992/03 - 2010/12
55026	100 m	145.01	-42.08	BOM	1998/01 - 2013/12
55028*	15 m	145.71	-16.73	QLD	1975/05 - 2013/12
55029*	18 m	147.05	-19.16	QLD	1975/11 - 2011/12

55031*	29 m	149.54	-21.05	QLD	1975/09 - 2013/12
55032*	10 m	149.27	-21.22	QLD	1977/03 - 2013/12
55033*	22 m	151.07	-23.31	QLD	1996/07 - 2011/12
55035*	73 m	153.62	-27.46	QLD	1976/10 - 2011/12
55036*	18 m	153.44	-27.96	QLD	1987/02 - 2013/12
55040	80 m	136.62	-36.07	BOM	2000/11 - 2013/12
56002*	110 m	116.12	-19.59	Woodside Energy Ltd.	1991/01 - 2006/12
56004	–	114.91	-30.29	WA	1997/10 - 2005/12
56005	–	115.40	-32.11	WA	1994/01 - 2005/12
56006	–	114.76	-33.53	WA	1999/05 - 2005/12
56008	–	115.69	-31.98	WA	1994/08 - 2006/05
56010	–	121.96	-33.93	WA	1982/12 - 1983/12
Bowen	–	148.28	-19.93	QLD	1978/09 - 1986/05
Cape Bridgewater*	60 m	141.24	-38.37	Sustainability Victoria	2011/04 - 2013/01
Carnegie	24 m	115.65	-32.25	Carnegie Wave Energy Ltd.	2009/03 - 2013/10
Cleveland Bay	–	146.90	-19.19	QLD	1993/01 - 1996/08
Dawesville	–	115.55	-32.60	WA	1985/04 - 1986/10
Enfield*	390 m	114.01	-21.51	Woodside Energy Ltd.	2007/01 - 2013/11
Kirra	–	153.53	-28.16	QLD	1988/08 - 1998/02
Lucinda	–	146.38	-18.52	OLD	1995/03 – 1996/05
Moreton Bay	–	153.20	-27.25	QLD	2000/10 - 2010/06
Oakajee	–	114.57	-28.59	WA	1998/06 - 2000/12
Port Campbell*	60 m	142.78	-38.72	Sustainability Victoria	2011/04 - 2013/01
Port Fairy*	30 m	142.17	-38.40	Biopower Systems	1997/01 - 2010/12
Weipa	–	141.74	-12.68	QLD	1978/12 - 2009/01
Woorim	–	153.21	-27.07	QLD	1988/09 - 2003/08

Table 5 and Fig. 9 show that there were noticeable gaps in the spatial in-situ observation coverage, e.g. northwest shelf, Great Australian Bight, and in the time coverage (Fig. 10), with 11 stations having less than 10 years available data. Additionally, only 12 of the 36 wave recorders had directional capability, the others only capable of measuring Significant Wave Height (Hs), Peak Period (Tp). Of the stations used in this study, 32 were operated by State or Federal authorities and four were operated by commercial enterprises (Woodside Energy Ltd. (2), Carnegie Wave Energy Ltd. and Biopower Systems).

Fig 10. Time plot of in-situ wave observations used in the ARENA study.

5. Wave models

Operational Wave models

The Bureau operates the AUSWAVE forecasting system (http://www.bom.gov.au/nwp/doc/auswave/data.shtml). This currently consists of two models, a Global model, AUSWAVE-G, and a nested regional model, AUSWAVE-R, details below. Both are based on version 4.18 of NOAA WAVEWATCH III (http://polar.ncep.noaa.gov/waves/wavewatch/).

Model	Domain	Resolution	Forecast period
AUSWAVE-G	Global (78°S-78°N, 0°E-359°E)	0.25°	240 hours
AUSWAVE-R	Regional (60°S-12°N, 69°E-180°E)	0.1°	72 hours

Operational runs utilise surface wind data from the Australian Community Climate and Earth-System Simulator (ACCESS) - ACCESS-G and ACCESS-R respectively. Model runs are conducted twice a day (0000, 1200 UTC) for ACCESS-G and 4 times a day (0000, 0600, 1200, 1800 UTC) for ACCESS-R. Standard parameters of wave height, period and direction are given at 3-hourly (AUSWAVE-G) and 1-hourly (AUSWAVE-R) intervals for wind waves, two swell partitions and combined wind and swell. Data in grib2 or netCDF is available via FTP to registered users. The Bureau used to issue Quarterly Summaries including details of the operational wave models' performance, but these ceased in 2013.

NOAA WaveWatch III also provides Global 180-hour forecasts at 0.5 degree resolution. These data can be downloaded from http://nomads.ncep.noaa.gov/. These forecasts are routinely used by surfing/sailing websites e.g. MarineWeather, BuoyWeather, MagicSeaweed, Swellnet.

NSW OEH have, in association with Cardno and Baird Australia, have established a nested modelling system involving WaveWatch III and SWAN to simulate historical and potential future coastal wave climates, detailed by Kinsela et al (2014) [NSW COASTAL OCEAN WAVE MODEL: INVESTIGATING SPATIAL AND TEMPORAL VARIABILITY IN COASTAL WAVE CLIMATES, M Kinsela, D Taylor, D Treloar, J Dent, S Garber, T Mortlock, I Goodwin. 2014] and available at www.coastalconference.com/2014/papers2014/Michael%20Kinsela.pdf. A recent update by Kinsela at the ACOMO 2016 conference (http://imos.org.au/acomo2016.html) described a wave transformation toolkit based on the hindcast output from the WWIII-Swan modelling system and the deepwater MHL observed waves and forecasts from NOAA WW-III to produce short term detailed forecasts for all NSW nearshore coastal regions. Operational forecasts are available from http://forecast.waves.nsw.gov.au.

The main reasons put forward for the development of this system are:

- Efficient calculation of nearshore wave conditions in all NSW coastal waters
- Improved understanding of spatial and temporal wave climate variability
- Support for state wide analyses of coastal hazards and risk assessment
- Reduced waste in developing site-specific wave transform tables
- Education platform for recreational coastal users and students
- Platform for development of coastal hazard forecast tools

A critical component noted in this work is the need for access to the highest resolution nearshore bathymetry.

Non-operational wave models

Wave models are used for a variety of reasons by different operators in Australia. For example

- A coupled wave/surge model for Australia was presented by Janekovic et al at ACOMO 2016 (http://imos.org.au/fileadmin/user_upload/shared/IMOS%20General/ACOMO/ACOMO_2016/presentations/day1/Yasha_Hetzel_IvicaCanberra_storm_surge.pdf) which focussed on the role of wave setup on water levels associated with cyclones.
- Wave models to investigate sand and sediment transport in SA Gulfs are described in James (2013) [James, C. (2013) Chapter 2: A wave model for Spencer Gulf. In: Middleton, J. F. (Ed.), PIRSA Initiative II --Carrying capacity of Spencer Gulf: hydrodynamic and biogeochemical measurement, modelling and monitoring. FRDC Project 009/046. South Australian Research & Development Institute (Aquatic Sciences), Adelaide.]
- Morim et al (2014) compared wave energy estimates near the coast from available wave models and showed both under and overestimation of significant wave height (http://doi.org/10.1016/j.ijome.2014.09.002).
- Behrens et al (2015) used the NOAA WaveWatch3 archive (February 1997 to January 2010) to evaluate the performance of different wave energy convertors and their potential contribution to the energy market (http://dx.doi.org/10.1016/j.renene.2015.03.076).

6. Wave climatologies

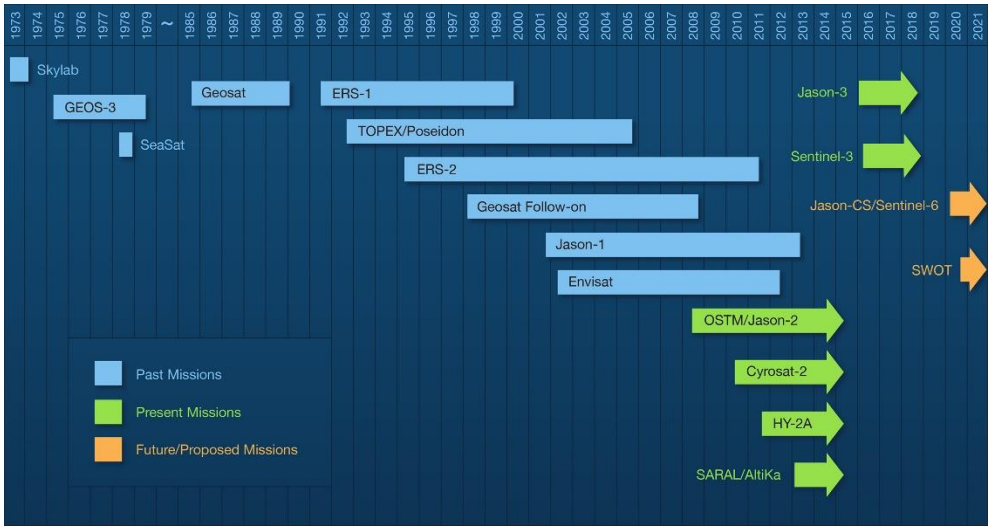
Model climatologies

The CAWCR wave hindcast (mentioned previously) provides a multi-decadal depiction of the wave field, continuous in both space and time, and thus able to provide robust descriptions of spatial and temporal variability of the wave climate. The hindcast is a global implementation of the 3rd generation spectral wave model WAVEWATCH III® (Tolman HL (2014) The WAVEWATCH III Development Group, User manual and system documentation version 4.18 Tech Note 316, NOAA/NWS/NCEP/MMAB, 282 pp), with a series of nested high resolution computational grids in the Australian and South Pacific regions, described by Durrant et al., 2014 (http://www.cawcr.gov.au/technical-reports/CTR_070.pdf). The CAWCR hindcast archives, consisting of an extensive array of spectral and gridded bulk wave fields, are served via an OPeNDAP server (http://tds-mel.csiro.au/thredds/catalog.html) and also available as packaged products from the Bureau of Meteorology's climate services section. This dataset is in the top three accessed datasets across all of the CSIRO Data Access Portal, and has been continuously for the past 3 years since its release.

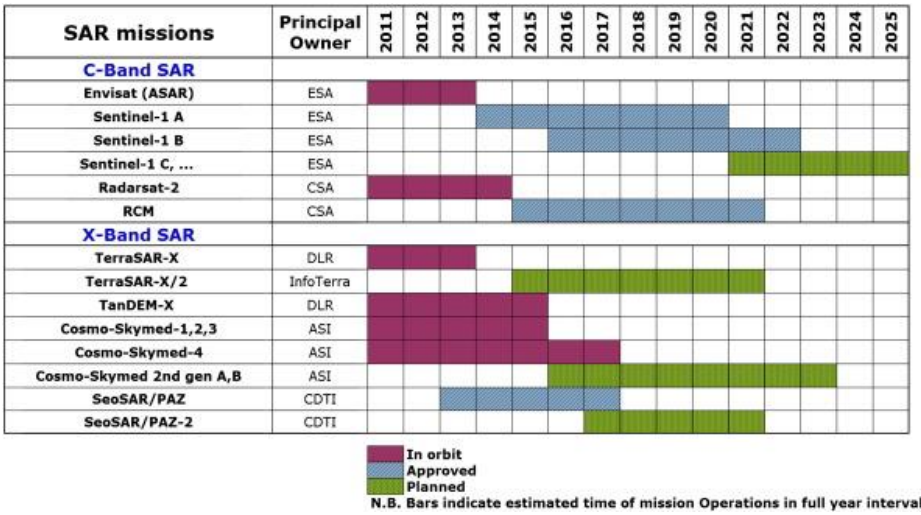
There is a 21st Century wind-wave climate projections dataset, which is also available via the CSIRO DAP (http://doi.org/10.4225/08/55C991CC3F0E8). This dataset also contains a coarse resolution (1degree) hindcast, which is used as a benchmark for the GCM forced simulations.

Satellite climatologies

The new IMOS SRS sub-facility (Hemer, Young, http://imos.org.au/facilities/srs/) will assemble wave climatologies building on the historical and present missions and will take advantage of the coming unprecedented era of satellite measured wave data. Presently, several altimeter missions are providing measurements of significant wave height (and potentially wave period; Jason-2, Jason-3, Sentinel-3, Cryosat-2, SARAL, HY-2). In 2018, several missions will be underway, capable of providing directional spectra of ocean waves. These include missions using synthetic aperture radar (SAR; the ESA Sentinel 1-A and Sentinel 1-B missions, and the CNSA GF-3 mission), and a new never-flown system of scanning beam low incidence scatterometer (the Surface Wave Investigation and Monitoring – SWIM – sensor aboard the French-Chinese CFOSAT mission). See figures below for major altimeter and SAR missions.



https://podaac.jpl.nasa.gov/Altimetric_Data_Information/Missions



https://doi.org/10.1016/j.rse.2011.08.028

It is worth mentioning the different sources of satellite-derived wave measurements: altimeter derived measurements, of which there is quite a good record of use in Australia; and Synthetic Aperture Radar data, of which very little attention has been given in Australia for a couple of reasons a) it is difficult data to work with, and b) access to data has been expensive. With the availability of Sentinel-1 data from the Copernicus Australia regional hub (http://www.copernicus.gov.au/), the new IMOS sub-facility looks to address this.

7. Summary

Gaps in observing capability

- Northwest shelf, which is covered by industry, but data not currently available
- Great Australian Bight, which is also covered by industry, but data not currently available
- East coast of Tasmania, where no coverage exists
- Deeper water, most wave recorders are close to the coast and not representative of the larger scale.

Data Access

- Whilst much of the wave observations data is accessible it takes some effort to locate and download it, a central repository could be more efficient. AODN is in the process of addressing this.
- Whilst the Bureau have access to most real-time wave observations they not easily accessible to others, although this is intended to be addressed by making these observations available through the AODN portal. Generally commercial observations, of which there are many, are not accessible.
- Wave model forecasts are available at the Bureau, as are numerical weather forecasts, but by subscription, not easily accessible. Hindcast data is readily accessible.

Objective of an observing system

It is a necessary requirement to have concrete research/applied aims in mind of why we need the wave measurements. However, there are many such purposes: wave energy, as mentioned above, is one example; for this buoys are needed everywhere to cover the Australian region uniformly.

Another application could be the improvement of wave forecast; for this, the buoys are not necessarily needed uniformly. Instead the reasons for a buoy network need prioritising; one perspective on this, put forward by Alex Babanin, is a priority list to capture: 1) swell; 2) tropical cyclones (particularly in the East where measurements outside the Reef are just absent); and for 3) identifying the gaps and faults in the forecast / hindcast. Other priorities will arise for different purposes, as described in the Introduction.

Acknowledgement

The authors thank the members of the surface wave working group for many useful comments on the drafts of this report.

Appendix 1 – Historical wave recordings from DoT WA

Location	Latitude N	Longitude E	Depth	Start	End	Data type	Make	Model
ESPERANCE	-33.840556	121.932778	12m	21/02/1980	04/03/1981	Analogue	Datawell	Waverider FL
ESPERANCE	-33.933333	121.958333	47m	13/12/1982	28/02/1983	Non-Directional	Datawell	Waverider FL
ESPERANCE	-33.933333	121.958333	47m	01/04/1983	01/04/1983	Non-Directional	Datawell	Waverider FL
ESPERANCE	-33.840556	121.932778	12m	17/02/2005	31/12/2005	Non-Directional	Datawell	Waverider FL
ESPERANCE	-34.000556	121.9	52m	18/06/2006	31/12/2011	Non-Directional	Datawell	Waverider FL
ESPERANCE	-34.000556	121.9	52m	01/01/2012	31/12/2015…	Directional	Datawell	Directional Waverider MK III
BREMER BAY	-34.425833	119.396944	6m	22/05/1992	12/12/1993	Non-Directional	Datawell	Waverider FL
BREMER BAY	-34.423889	119.405833	20m	22/05/1992	09/03/1993	Non-Directional	Datawell	Waverider FL
ALBANY	-35.031389	117.941944	13m	24/06/1981	12/09/1983	Analogue	Datawell	Waverider FL
ALBANY	-35.061666	117.981666	NA	25/07/2001	26/08/2001	Non-Directional	Datawell	Waverider FL
ALBANY	-35.031667	117.941667	13m	26/07/2001	21/03/2002	Non-Directional	Datawell	Waverider FL
ALBANY	-35.198056	117.721944	60m	26/07/2005	02/09/2008	Non-Directional	Datawell	Waverider FL
ALBANY	-35.198056	117.721944	60m	03/09/2008	31/12/2015…	Directional	Datawell	Directional Waverider MK III
AUGUSTA	-34.375	115.154444	8m	14/05/1987	02/09/1988	Analogue	Datawell	Waverider FL
AUGUSTA	-34.366389	115.169444	10m	02/09/1988	22/02/1990	Analogue	Datawell	Waverider FL
AUGUSTA	-34.3275	115.212778	13m	12/01/1989	15/08/1990	Non-Directional	Datawell	Waverider FL
CAPE NATURALISTE	-33.362222	114.775556	50m	28/05/1999	27/04/2004	Non-Directional	Datawell	Waverider FL
CAPE NATURALISTE	-33.534722	114.764444	50m	28/04/2004	10/02/2010	Non-Directional	Datawell	Waverider FL
CAPE NATURALISTE	-33.534722	114.764444	50m	11/02/2010	31/12/2015…	Directional	Datawell	Directional Waverider MK III
ROCKEY POINT	-33.549444	115.059444	7m	14/03/1979	18/10/1979	Analogue	Datawell	Waverider FL

ROCKEY POINT	-33.549444	115.059444	7m	22/04/1980	01/05/1981	Analogue	Datawell	Waverider FL
BUSSELTON	-33.601944	115.275556	14m	21/01/1977	07/12/1978	Analogue	Datawell	Waverider FL
BUNBURY	-33.296667	115.621111	16m	05/03/1975	03/06/1976	Analogue	Datawell	Waverider FL
BUNBURY	-33.295278	115.618333	16m	19/04/1977	19/06/1978	Analogue	Datawell	Waverider FL
BUNBURY	-33.298333	115.617778	16m	09/08/1978	05/10/1978	Analogue	Datawell	Waverider FL
BUNBURY	-33.298333	115.617778	16m	05/10/1978	23/03/1979	Analogue	Datawell	Waverider FL
BUNBURY	-33.298333	115.617778	16m	22/05/1979	02/05/1980	Analogue	Datawell	Waverider FL
BUNBURY	-33.298333	115.617778	16m	12/05/1980	22/12/1981	Analogue	Datawell	Waverider FL
DAWESVILLE	-32.598333	115.550833	25m	17/04/1985	31/10/1985	Non-Directional	Datawell	Waverider FL
DAWESVILLE	-32.598333	115.550833	25m	01/11/1985	21/10/1986	Non-Directional	Datawell	Waverider FL
DAWESVILLE	-32.605833	115.621944	10m	17/04/1985	24/08/1985	Non-Directional	Datawell	Waverider FL
DAWESVILLE	-32.100556	115.626667	10m	17/04/1985	23/04/1987	Non-Directional	Datawell	Waverider FL
MANDURAH	-32.4528	115.572216	30m	07/04/2015	07/04/2015…	Directional	Datawell	Directional Waverider MK III
KWINANA	-32.3	115.754444	NA	02/11/1993	06/12/1993	Analogue	Datawell	Waverider FL
COCKBURN	-32.107778	115.691667	14m	26/02/2008	7/10/2014	Non-Directional	Datawell	Waverider FL
FREMANTLE	-32.062222	115.724444	7m	05/06/1974	24/02/1975	Analogue	Datawell	Waverider FL
ROTTNEST ISLAND	-32.111389	115.401944	48m	17/08/1999	31/12/2004	Non-Directional	Datawell	Waverider FL
ROTTNEST ISLAND	-32.094167	115.407778	48m	14/09/2004	31/12/2015…	Directional	Datawell	Directional Waverider MK III
COTTESLOE	-31.977778	115.686667	17m	04/09/1999	25/02/2008	Non-Directional	Datawell	Waverider FL
COTTESLOE	-31.977778	115.686667	17m	14/02/2008	23/10/2014	Directional	Datawell	Directional Waverider MK III
COTTESLOE	-31.977778	115.686667	17m	24/10/2014	18/12/2015	Non-Directional	Datawell	Directional Waverider MK III

COTTESLOE	-31.977778	115.686667	17m	18/12/2015	31/12/2015…	Directional	Datawell	Directional Waverider MK III
HILLARYS	-31.828889	115.730278	6m	31/03/1987	20/05/1987	Analogue	Datawell	Waverider FL
SORRENTO	-31.826667	115.726667	8m	07/06/1984	17/10/1984	Analogue	Datawell	Waverider FL
MULLALOO	-31.762222	115.723889	7m	26/05/1977	03/03/1978	Analogue	Datawell	Waverider FL
GUILDERTON	-31.404722	115.427778	33m	11/04/1988	03/12/1988	Non-Directional	Datawell	Waverider FL
GUILDERTON	-31.359722	115.481944	10m	11/04/1988	19/07/1988	Non-Directional	Datawell	Waverider FL
LEDGE POINT	-31.134722	115.314444	26m	05/06/2002	18/10/2004	Non-Directional	Datawell	Waverider FL
JURIEN BAY	-30.292222	115.033611	11.5m	18/03/1981	23/09/1982	Analogue	Datawell	Waverider FL
JURIEN BAY	-30.291667	114.914444	42m	27/10/1997	22/06/1998	Analogue	Datawell	Waverider FL
JURIEN BAY	-30.291667	114.914444	42m	02/01/1998	23/10/2009	Non-Directional	Datawell	Waverider FL
JURIEN BAY	-30.291667	114.914444	42m	27/10/2009	31/12/2015…	Directional	Datawell	Directional Waverider MK III
DENISON	-29.261944	114.847222	20m	29/07/1974	12/12/1974	Analogue	Datawell	Waverider FL
DENISON	-29.261944	114.847222	20m	14/07/1975	28/10/1975	Analogue	Datawell	Waverider FL
DENISON	-29.272778	114.905833	14m	15/07/1975	06/07/1976	Analogue	Datawell	Waverider FL
DENISON	-29.275	114.914167	8m	29/10/1975	02/12/1976	Analogue	Datawell	Waverider FL
DENISON	-29.275	114.914167	8m	24/06/1976	15/11/1976	Analogue	Datawell	Waverider FL
GERALDTON	-28.757778	114.536667	10m	16/12/1976	12/05/1977	Analogue	Datawell	Waverider FL
GERALDTON	-28.757778	114.536667	10m	24/10/1977	09/02/1978	Analogue	Datawell	Waverider FL
GERALDTON	-28.759722	114.565556	12m	13/03/1980	30/01/1981	Analogue	Datawell	Waverider FL
GERALDTON	-28.756111	114.567222	12m	30/12/1983	01/01/1985	Analogue	Datawell	Waverider FL
GERALDTON	-28.758889	114.535556	27m	29/12/1983	19/01/1985	Non-Directional	Datawell	Waverider FL
GERALDTON	-28.758333	114.583611	10m	29/12/1983	19/01/1985	Non-Directional	Datawell	Waverider FL
GERALDTON	-28.765278	114.598611	6m	29/12/1983	31/12/1984	Non-Directional	Datawell	Waverider FL
OAKAGEE	-28.591111	114.565833	15m	12/03/1980	23/09/1981	Analogue	Datawell	Waverider FL
OAKAGEE	-28.590556	114.565833	18m	03/06/1998	14/12/2000	Non-Directional	Datawell	Waverider FL
CORAL BAY	-23.174321	113.744167	20m	22/12/2004	31/12/2004	Non-Directional	Datawell	Waverider FL

NINGALOO	-22.5625	113.65	47m	12/08/1987	11/04/1988	Non-Directional	Datawell	Waverider FL
NINGALOO	-22.5625	113.65	47m	14/07/1988	01/10/1988	Non-Directional	Datawell	Waverider FL
EXMOUTH	-21.699444	114.098611	54m	04/10/2006	31/12/2011	Directional	Datawell	Directional Waverider MK III
Location	Latitude	Longitude	Depth	Start	End	Make	Model	Comment
ESPERANCE - DUKE OF ORLEANS BAY	-33.918817	122.591317	8.4m	27/11/2007	11/03/2008	NORTEK	1 MHz AWAC	
				12/03/2008	09/07/2008	NORTEK	1 MHz AWAC	Instrument pitch changed during deployment
				09/07/2008	09/10/2008	NORTEK	1 MHz AWAC	No Data Retrieved
				09/10/2008	19/01/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				19/01/2009	27/05/2009	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				27/05/2009	23/09/2009	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
ESPERANCE - BANDY CREEK	-33.840556	121.932778	12.0m	13/06/2006	18/09/2006	NORTEK	1 MHz AWAC	No Comment Recorded

ESPERANCE - TANKER BERTH NO. 1	-33.852233	121.911333	12.0m	28/09/2006	23/01/2007	NORTEK	1 MHz AWAC	No Comment Recorded
				24/09/2009	03/02/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				03/02/2010	13/05/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				13/05/2010	22/09/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				22/09/2010	24/01/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				24/01/2011	10/06/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				10/06/2011	05/10/2011	NORTEK	1 MHz AWAC	No data due to instrument failure
				05/10/2011	16/02/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				16/02/2012	21/05/2012	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				21/05/2012	17/08/2012	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				17/08/2012	07/11/2012	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				07/11/2012	08/02/2013	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				08/02/2013	29/05/2013	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				29/05/2013	11/09/2013	NORTEK	1 MHz AWAC	New sampling rate 1Hz

				11/09/2013	05/12/2013	NORTEK	1 MHz AWAC	No data due to instrument failure
				05/12/2013	12/03/2014	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment; New sampling rate 1Hz
				12/03/2014	17/03/2014	NORTEK	1 MHz AWAC	New sampling rate 1Hz
				17/06/2014	17/10/2014	NORTEK	1 MHz AWAC	New sampling rate 1Hz
HOPETOUN	-33.954167	120.125967	4.0m	14/08/2013	13/09/2013	NORTEK	1 MHz AWAC	No Comment Recorded
AUGUSTA - LOCATION NO. 1 - FLINDERS BAY	-34.354166	115.170000	10m	17/11/2009	08/03/2010	NORTEK	1 MHz AWAC	
				03/03/2010	26/05/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				24/05/2010	07/09/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				06/09/2010	25/11/2010	NORTEK	1 MHz AWAC	Monitoring Terminated
				21/12/2011	02/04/2012	NORTEK	1 MHz AWAC	New Monitoring Program
				29/03/2012	25/06/2012	NORTEK	1 MHz AWAC	No Comment Recorded

				22/06/2012	19/10/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				18/10/2012	29/01/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				25/01/2013	18/04/2013	NORTEK	1 MHz AWAC	
				17/04/2013	12/07/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				12/07/2013	01/10/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				27/09/2013	21/02/2014	NORTEK	1 MHz AWAC	Deployment terminated
AUGUSTA - FLINDERS BAY BOAT HARBOUR	-34.353444	115.168194	10.0m	27/09/2013	08/11/2013	NORTEK	1 MHz AWAC	
BUSSELTON - LOCATION NO. 1	-33.601933	115.275550	14.0m	14/11/2006	05/02/2007	NORTEK	1 MHz AWAC	No Comment Recorded
				02/02/2007	15/06/2007	NORTEK	1 MHz AWAC	No Comment Recorded
				09/05/2007	19/09/2007	NORTEK	1 MHz AWAC	No Comment Recorded
				28/09/2007	07/01/2008	NORTEK	1 MHz AWAC	No Comment Recorded
				08/01/2008	10/04/2008	NORTEK	1 MHz AWAC	No Comment Recorded

BUSSELTON - LOCATION NO. 2	-33.597567	115.296750	14.5m	08/04/2008	05/08/2008	NORTEK	1 MHz AWAC	No Comment Recorded
				04/08/2008	03/11/2008	NORTEK	1 MHz AWAC	No Comment Recorded
				31/10/2008	25/02/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				20/02/2009	03/07/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				14/07/2009	18/11/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				17/11/2009	05/03/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				03/03/2010	31/05/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				24/05/2010	13/09/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				24/05/2010	13/09/2010	NORTEK	1 MHz AWAC	No Comment Recorded
				09/09/2010	17/01/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				12/01/2011	07/06/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				01/06/2011	30/08/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				26/08/2011	22/12/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				21/12/2011	30/03/2012	NORTEK	1 MHz AWAC	No Comment Recorded

				29/03/2012	26/06/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				22/06/2012	29/10/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				26/10/2012	21/02/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				20/02/2013	11/06/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				11/06/2013	29/06/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				22/10/2013	20/02/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				20/02/2014	16/07/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				16/07/2014	11/12/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				11/12/2014	08/06/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				08/06/2015	27/11/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				27/11/2015	30/03/2016	NORTEK	1 MHz AWAC	No Comment Recorded
				30/03/2016	14/09/2016	NORTEK	1 MHz AWAC	No Comment Recorded
				14/09/2016	20/12/2016	NORTEK	1 MHz AWAC	No Comment Recorded
CASURINA HARBOUR	-33.311861	115.640361	3.8m	29/06/2015	07/08/2015	NORTEK	1 MHz AWAC	

BUNBURY INNER								
CASURINA HARBOUR BUNBURY OUTER	-33.310628	115.643969	5.3m	29/06/2015	24/08/2015	NORTEK	1 MHz AWAC	
				24/08/2015	18/12/2015	NORTEK	1 MHz AWAC	
				18/12/2015	12/05/2016	NORTEK	1 MHz AWAC	
				12/05/2016	14/09/2016	NORTEK	1 MHz AWAC	
MANDURAH NORTH	-32.468133	115.720733	10.0m	11/06/2014	24/10/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				24/10/2014	13/03/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				13/03/2015	05/11/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				05/11/2015	04/03/2016	NORTEK	1 MHz AWAC	No Comment Recorded
MANDURAH SOUTH	-32.491300	115.708767	10.0m	12/06/2014	24/10/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				24/10/2014	13/03/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				13/03/2015	05/11/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				05/11/2015	04/03/2016	NORTEK	1 MHz AWAC	Processed data have been adjusted due to

								the wrong temperature setting
KWINANA	-32.249389	115.752383	5.0m	16/12/2005	08/03/2006	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				09/03/2006	21/07/2006	NORTEK	1 MHz AWAC	No Comment Recorded
				18/08/2006	07/11/2006	NORTEK	1 MHz AWAC	No Comment Recorded
PORT BEACH, FREMANTLE	-32.038311	115.741111	5.0m	16/12/2005	08/03/2006	NORTEK	1 MHz AWAC	No Comment Recorded
				09/03/2006	04/08/2006	NORTEK	1 MHz AWAC	No Comment Recorded
ALKIMOS - LOCATION NO. 1	-31.628055	115.664166	6.0m	06/06/2008	01/10/2008	NORTEK	1 MHz AWAC	No Comment Recorded
				28/09/2008	12/01/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				09/01/2009	30/04/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				29/04/2009	27/08/2009	NORTEK	1 MHz AWAC	No Comment Recorded
				26/08/2009	11/12/2009	NORTEK	1 MHz AWAC	No Comment Recorded
ALKIMOS - LOCATION NO. 2	-31.620000	115.658611	6.0m	13/06/2008	30/09/2008	NORTEK	1 MHz AWAC	No Comment Recorded

TWO ROCKS	-31.494444	115.568055	10.0m	01/02/2013	12/04/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				11/04/2013	05/08/2013	NORTEK	1 MHz AWAC	Data issue found in this deployment. Use with caution
				02/08/2013	21/11/2013	NORTEK	1 MHz AWAC	Be aware that the instrument was turned over from 01/09/2013 to 21/11/2013
				21/11/2013	27/02/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				26/02/2014	06/06/2014	NORTEK	1 MHz AWAC	
				05/06/2014	15/09/2014	NORTEK	1 MHz AWAC	Data not valid after 17/6/14 due to instrument turning over
				12/09/2014	05/12/2014	NORTEK	1 MHz AWAC	
				05/12/2014	15/06/2015	NORTEK	1 MHz AWAC	Data have been adjusted due to the wrong temperature setting
				15/06/2015	09/10/2015	NORTEK	1 MHz AWAC	Deployment 09 does not exist,

								but the data is continuous
				09/10/2015	04/02/2016	NORTEK	1 MHz AWAC	
				04/02/2016	11/05/2016	NORTEK	1 MHz AWAC	
TWO ROCKS MARINA	-31.496516	115.580633	4.1m	05/06/2014	25/07/2014	NORTEK	1 MHz AWAC	
				04/02/2016	28/04/2016	NORTEK	1 MHz AWAC	
SEA BIRD	-31.244628	115.434094	7.0m	30/01/2003	03/04/2003	NORTEK	1 MHz AWAC	No Comment Recorded
				08/04/2003	08/07/2003	NORTEK	1 MHz AWAC	No Comment Recorded
LEDGE POINT - LOCATION 4	-31.127144	115.380917	7.0m	31/01/2003	02/04/2003	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				09/04/2003	01/07/2003	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				07/08/2003	02/10/2003	NORTEK	1 MHz AWAC	No Comment Recorded
				07/11/2003	13/02/2004	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment

				25/02/2004	19/05/2004	NORTEK	1 MHz AWAC	No Comment Recorded
				15/06/2004	16/09/2004	NORTEK	1 MHz AWAC	No Comment Recorded
LEDGE POINT - LOCATION 5	-31.099444	115.366388	5.7m	07/08/2003	02/10/2003	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				07/11/2003	13/02/2004	NORTEK	1 MHz AWAC	Instrument pitch/roll changed during deployment
				25/02/2004	19/05/2004	NORTEK	1 MHz AWAC	No Comment Recorded
				15/06/2004	16/09/2004	NORTEK	1 MHz AWAC	No Comment Recorded
JURIEN BAY WEST	-30.286933	115.039083	8.0m	19/03/2014	26/05/2014	NORTEK	1 MHz AWAC	
				18/07/2014	02/12/2014	NORTEK	1 MHz AWAC	
				26/11/2014	27/02/2015	NORTEK	1 MHz AWAC	
				26/02/2015	27/07/2015	NORTEK	1 MHz AWAC	
				24/07/2015	02/11/2015	NORTEK	1 MHz AWAC	
				29/10/2015	21/01/2016	NORTEK	1 MHz AWAC	

JURIEN BAY NORTH	-30.275717	115.039433	7.4m	29/05/2014	03/10/2014	NORTEK	1 MHz AWAC	
JURIEN BAY SOUTH	-30.295517	115.022883	13.6m	29/05/2014	01/10/2014	NORTEK	1 MHz AWAC	
				01/10/2014	26/02/2015	NORTEK	1 MHz AWAC	
				26/02/2015	24/07/2015	NORTEK	1 MHz AWAC	
				24/07/2015	29/10/2015	NORTEK	1 MHz AWAC	Processed data have been adjusted due to the wrong temperature setting
				29/10/2015	20/01/2016	NORTEK	1 MHz AWAC	
GERALDTON BATAVIA MARINA	-28.766944	114.610222	4.6m	01/08/2014	27/11/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				27/11/2014	26/03/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				26/03/2015	13/08/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				13/08/2015	03/12/2015	NORTEK	1 MHz AWAC	No Comment Recorded
				03/12/2015	23/03/2016	NORTEK	1 MHz AWAC	No Comment Recorded
KALBARRI ENTRANCE	-27.708683	114.160067	3.5m	09/08/2006	20/11/2006	NORTEK	1 MHz AWAC	Half buried in sand

CORAL BAY - LOCATION A	-23.166500	113.756667	7.0m	21/12/2004	30/03/2005	NORTEK	1 MHz AWAC	No Comment Recorded
CORAL BAY (INNER) - LOCATION NO. 6	-23.156700	113.764400	3.0m	01/06/2004	09/06/2004	NORTEK	1 MHz AWAC	No Comment Recorded
CORAL BAY (OUTER) - LOCATION NO. 7	-23.155400	113.756800	6.0m	01/06/2004	09/06/2004	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME P2	-18.059950	122.198283	5.8m	20/02/2011	15/05/2011	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME P5	-18.031233	122.213000	10.0m	20/02/2011	18/05/2011	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME P4	-18.006166	122.221000	10.0m	31/03/2011	18/05/2011	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME - LOCATION: D	-17.995617	122.220900	5.0m	13/12/2005	09/01/2006	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME - C-F-E-A	-17.989567	122.226583	1.0m	09/11/2004	06/03/2005	NORTEK	1 MHz AWAC	note Locations C,F,E,A are all in Broome01.wpr. C= 09/11/2004 To 07/12/2004 (17 59 44 S , 122 13 09 E) F= 07/12/2004 To 07/01/2005(18 00 10 S ,122 11 51 E) E= 07/01/2005 To

								07/02/2005 (18 00 04 S,122 12 52 E) A= 07/02/2005 To 06/03/2005 (17 59 22 S, 122 13 36 E)
BROOME - LOCATION NO. 1	-18.000833	122.215361	1.5m	08/09/2010	10/12/2010	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME P3 (FORMERLY BROOME P1)	-18.001033	122.215483	1.5m	23/02/2011	18/05/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				18/05/2011	16/08/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				16/08/2011	14/11/2011	NORTEK	1 MHz AWAC	No Comment Recorded
				14/11/2011	12/02/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				12/02/2012	20/05/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				20/05/2012	20/08/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				20/08/2012	22/11/2012	NORTEK	1 MHz AWAC	No Comment Recorded
				22/11/2012	15/02/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				31/08/2013	20/08/2013	NORTEK	1 MHz AWAC	No Comment Recorded

				20/08/2013	18/11/2013	NORTEK	1 MHz AWAC	No Comment Recorded
				18/11/2013	25/02/2014	NORTEK	1 MHz AWAC	No Comment Recorded
				25/02/2014	23/05/2014	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME - LOCATION NO. 2	-18.001278	122.215528	7.8m	10/12/2010	18/02/2011	NORTEK	1 MHz AWAC	
BROOME - LOCATION G	-18.003433	122.196583	5.0m	11/11/2005	09/12/2005	NORTEK	1 MHz AWAC	No Comment Recorded
BROOME P1	-17.992133	122.181350	10.0m	20/02/2011	18/05/2011	NORTEK	1 MHz AWAC	No Comment Recorded

Appendix – 2 QLD Real-time station details (data collected from https://www.qld.gov.au/environment/coasts-waterways/beach/waves-sites/)

Location	Latitude	Longitude	Depth	Deployed		Maker	Instrument	Comment
TWEED HEADS	28.1818° S	153.5759° E	22m	13/01/1995		Datawell	0.9m GPS Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the Tweed River Sand Bypassing Project
GOLD COAST	27.9652° S	153.4426° E	17m	20/02/1987		Datawell	Directional Waverider Buoy	Jointly operated by the Department of Science, Information Technology, Innovation and the Arts and the Gold Coast City Council
BRISBANE	27.4872° S	153.6317° E	70m	30/10/1976		Datawell	0.9m Waverider Buoy	
NORTH MORETON BAY	26.8985° S	153.2788° E	35m	08/03/2010		Datawell	0.9m GPS Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the Port of Brisbane Corporation
CALOUNDRA	26.8476° S	153.1557° E	12m	01/05/2013		Datawell	0.9m Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the Port of Brisbane Corporation

MOOLOOLABA	26.566° S	153.1812° E	32m	20/04/2000		Datawell	0.9m GPS Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the Department of Transport and Main Roads
BUNDABERG	24.6718° S	152.501° E	18m	08/09/2015		Datawell	0.7m Waverider Buoy	
GLADSTONE	23.8956° S	151.5024° E	16m	23/07/2009		Datawell	0.7m Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the Gladstone Ports Corporation
EMU PARK	23.3053° S	151.0713° E	19m	24/07/1996		Datawell	0.9m Waverider Buoy	
HAY POINT	21.2715° S	149.3102° E	10m	30 February 1993 ?????		Datawell	0.9m GPS Waverider Buoy	Jointly operated by the Department of Science, Information Technology and Innovation and the North Queensland Bulk Ports Corporation Limited
MACKAY	21.04° S	149.546° E	30m	20/09/1975		Datawell	0.9m Waverider Buoy	
ABBOT POINT	19.8663° S	148.0974° E	14m	11/01/2012		Datawell	Waverider Buoy	Jointly operated by the Department of Science, Information

								Technology, Innovation and the Arts and the North Queensland Bulk Ports Corporation Limited.
TOWNSVILLE	19.1592° S	147.0593° E	17m	16/07/1975		Datawell	0.9m Waverider Buoy	
CAIRNS	16.7305° S	145.7152° E	12m	02/05/1975		Datawell	0.7m Waverider Buoy	
ALBATROSS BAY (WEIPA)	12.688° S	141.6847° E	10m	25/11/2008		Datawell	0.9m Waverider Buoy	Jointly operated by the Department of Science, Information Technology, Innovation and the Arts and the North Queensland Bulk Ports Corporation Limited

Appendix – 3 QLD historical wave recordings

Location	Latitude	Longitude		Start	End
Abbot Point	19.8663° S	148.0974° E		07/05/1977	28/06/2000
Bar Cutting Wave Pole	27.4° S	153.15° E		01/07/1997	30/09/2002
Bargara	24.8312°S	152.4592° E		18/02/1986	10/04/1986
Bilinga	28.1600° S	153.5100° E		06/10/2007	02/07/2008
Bowen	20.0015° S	148.2262° E		14/09/1978	29/05/1986
Bramston Beach	17.3632° S	146.0184° E		16/12/1981	28/10/1985
Bribie Island	26.9861° S	153.1325° E		15/06/1983	12/04/1985
Burnett Heads	24.7769° S	152.4043° E		05/05/1976	04/10/1990
Cairns (Clifton Beach Nearshore)	16.7705° S	145.6717° E		18/03/1981	12/07/1982
Cairns (Holloways Beach Nearshore)	16.8422° S	145.7392° E		18/03/1981	12/07/1982
Cairns (Yorkeys Knob Nearshore)	16.8120° S	145.7210° E		18/03/1981	12/07/1982
Cleveland Bay	19.2181° S	146.9222° E		05/01/1993	22/08/1996
Coonarr	24.9745° S	152.4497° E		18/02/1986	04/08/1986
Dunk Island	17.9446° S	146.1533° E		17/12/1998	12/11/2002
Hayman Island	20.0504° S	148.8891° E		26/10/1995	14/10/1996
Heron Island Blue Pools	23.4344° S	151.9225° E		16/03/1996	14/05/1997
Heron Island Wistari Channel	23.4541° S	151.9168° E		16/03/1996	14/05/1997
Hervey Bay	25.2882° S	152.7677° E		03/03/1977	13/02/1986
Holloways Beach	16.8422° S	145.7392° E		03/12/1997	30/06/1998
Karumba inshore	17.3719° S	140.7086° E		01/08/1994	31/07/1995
Karumba offshore	17.0858° S	140.2969° E		04/08/1994	20/01/1995
Kirra	28.1578° S	153.5288° E		26/08/1988	10/02/1998
Lindeman Island	20.3904° S	149.0787° E		18/10/1996	20/05/1997
Long Island	20.4516° S	148.901° E		20/05/1997	30/09/1997

Low Islets	16.3938° S	145.5737° E		01/11/1998	10/08/1999
Lucinda	18.5157° S	146.3833° E		02/03/1995	13/05/1996
Mackay - Blacks Beach	21.0433° S	149.1933° E		12/05/1987	30/04/2001
Mackay - Bucasia Beach	21.0° S	149.1833° E		10/02/1988	11/05/1989
Mackay - Far Beach	21.1933° S	149.2411° E		06/02/1990	18/02/1991
Mackay - Slade Point	21.1156° S	149.2333° E		11/03/1986	07/04/1987
Mackay Inner	21.0147° S	149.3387° E		22/11/2000	31/01/2002
Moore Park	24.7083° S	152.2856° E		18/02/1986	04/08/1986
Moreton Bay	27.2508° S	153.1992° E		19/10/2000	24/06/2010
Nerang	27.94° S	153.4386° E		13/07/1984	09/05/1986
Noosa Nearshore Buoy 19	26.3833° S	153.0833° E		14/11/1980	21/06/1981
Noosa Nearshore Buoy 26	26.3835° S	153.0889° E		09/02/1989	21/08/1992
Noosa Offshore Buoy 20	26.3833° S	153.1333° E		14/11/1980	22/01/1981
Repulse Bay	20.628° S	148.8589° E		02/06/1994	22/10/1995
Rosslyn Bay Nearshore	23.1625° S	150.7875° E		13/02/1987	13/04/1987
Rosslyn Bay Offshore	23.0792° S	150.9292° E		21/02/1987	20/04/1987
Toogoom	25.23° S	152.7067° E		01/05/1985	22/08/1985
Weipa	12.6771° S	141.7416° E		22/12/1978	12/01/2009
Woodgate	25.1° S	152.5667° E		05/09/1985	05/02/1986
Woorim	27.0712° S	153.208° E		24/09/1988	15/08/2003
Yabulu	19.1392° S	146.6453° E		19/03/1986	14/04/1987
Yeppoon	23.1167° S	151.0667° E		19/12/1974	06/03/1978

Appendix – 4 New South Wales historical inshore wave data collection stations

Wave Data Site	Instrument	Location		Water Depth (m)	Data Available	
		Latitude (E)	**Longitude (S)**		**First Date**	**Last Date**
Tweed River	EWS*	28° 10' 16"	153° 32' 55"	4	20-Jan-1995	27-Nov-2008
Tweed Heads Inshore	Waverider buoy	28° 10' 38"	153° 33' 48"	13	21-Apr-1989	08-Nov-1989
Tweed Heads	Marsh McBirney	28° 10' 38"	153° 33' 48"	13	09-Jun-1988	10-Oct-1989
Cook Island	Marsh McBirney / S4	28° 11' 38"	153° 34' 14"	12	09-Jun-1988	25-Oct-1989
Fingal Head	Marsh McBirney / S4	28° 12' 30"	153° 34' 17"	12	09-Jun-1988	25-Oct-1989
Coffs Harbour Entrance	Marsh McBirney	30° 18' 35"	153° 09' 09"	9	04-Dec-1986	31-Oct-1987
Coffs Harbour Jetty	EWS	30° 18' 26"	153° 08' 38"	7	05-Nov-1986	15-Jan-1996
Coffs Harbour Jetty MMcB	Marsh McBirney	30° 18' 26"	153° 08' 38"	7	04-Dec-1986	20-Jan-1987
Coffs Harbour Boat Ramp	Marsh McBirney	30° 18' 40"	153° 08' 32"	6	21-Jan-1987	08-Mar-1987
Coffs Harbour Quarry	Marsh McBirney	30° 18' 43"	153° 08' 50"	6	10-Mar-1987	27-Apr-1987
Muttonbird Island West	Marsh McBirney	30° 18' 30"	153° 08' 48"	6	29-Apr-1987	17-Jun-1987
Coffs Inner Hbr Entrance	Marsh McBirney	30° 18' 21"	153° 08' 36"	4	19-Jun-1987	04-Aug-1987
Muttonbird Island East	Marsh McBirney	30° 18' 27"	153° 09' 14"	11	14-Aug-1987	06-Oct-1987
Muttonbird Island South	Marsh McBirney	30° 18' 31"	153° 09' 00"	7	07-Oct-1987	31-Oct-1987
Coffs Harbour Central	Marsh McBirney	30° 18' 38"	153° 08' 41"	8	05-Nov-1987	25-Nov-1987
Coffs Inner Harbour	EWS	30° 18' 16"	153° 08' 41"	4	16-Jan-1996	08-Oct-2011
Crowdy Head Harbour	EWS	31° 50' 28"	152° 44' 59"	2	07-Nov-1986	16-Jul-2012
Jimmys Beach	EWS	32° 40' 56"	152° 09' 52"	3	16-Dec-1983	08-Oct-1985
Nelson Bay	EWS	32° 43' 11"	152° 08' 36"	6	20-Jan-1981	18-Jun-1986
Nelson Bay West Point	EWS	32° 43' 10"	152° 08' 26"	5	19-Jun-1986	20-Apr-1988
Swansea	EWS	33° 05' 20"	151° 39' 41"	2	17-Dec-1987	12-Apr-1991
Wamberal Beach	Directional Waverider	33° 25' 56"	151° 27' 07"	11	05-Aug-2011	16-Mar-2012
Broken Bay	Waverider buoy	33° 33' 41"	151° 20' 35"	24	30-Jan-1981	02-Jun-1983

Broken Bay Current	Marsh McBirney	33° 33' 55"	151° 20' 35"	24	23-Nov-1979	15-Feb-1983
Palm Beach	Marsh McBirney	33° 35' 34"	151° 20' 12"	24	19-Jun-1981	14-Sep-1982
Mackerel Beach	EWS	33° 35' 31"	151° 18' 01"	2	17-Aug-1988	15-Oct-1989
Narrabeen Beach	Directional Waverider	33° 43' 17"	151° 18' 15"	10	27-Jul-2011	14-Nov-2011
Long Reef	Waverider buoy	33° 43' 59"	151° 19' 27"	21	27-Jul-2011	14-Nov-2011
Port Hacking Seaward	EWS	34° 04' 43"	151° 08' 42"	3	06-Sep-1983	04-Jan-2014
Deeban Spit	EWS	34° 04' 45"	151° 08' 03"	2	15-Sep-1983	03-Oct-1986
Port Hacking S"ward MMcB	Marsh McBirney	34° 04' 43"	151° 08' 42"	3	06-Sep-1983	17-Nov-1986
Deeban Spit MMcB	Marsh McBirney	34° 04' 45"	151° 08' 03"	2	06-Sep-1983	28-May-1985
Burraneer Point MMcB	Marsh McBirney	34° 04' 30"	151° 08' 00"	6	06-Sep-1983	16-Dec-1985
Port Kembla Inshore	Waverider buoy	34° 27' 33"	150° 54' 36"	18	31-May-1978	26-Jul-1982
Jervis Bay North	EWS	35° 02' 24"	150° 40' 27"	6	11-Nov-1981	03-Jul-1989
Jervis Bay South	EWS	35° 03' 05"	150° 40' 52"	8	01-Sep-1981	18-Oct-1983
Batemans Bay Inshore	EWS	35° 43' 25"	150° 12' 42"	7	26-Feb-1987	08-Dec-1990
Eden Inshore	Waverider buoy	37° 04' 31"	149° 54' 17"	9	24-Nov-1984	11-May-1987
Eden Harbour	EWS	37° 04' 25"	149° 54' 21"	4	24-Nov-1984	13-Nov-2011

* Electromagnetic wave and tide monitoring systems (EWS)