Integrated Marine Observing System

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IMOS Coastal Wave Buoy Facility

Data quality control documentation for coastal wave buoys

Version 1.0

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NCRIS National Research Infrastructure for Australia
An Australian Government Initiative

Australia's Integrated Marine Observing System (IMOS) is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the Univeristy of Tasmania as Lead Agent.

IMOS acknowledges the Traditional Custodians and Elders of the land and sea which we work and observe, and recognise their unique connection to land and sea. We pay our respects to Aboriginal and Torres Strait Islander people past and present.

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Table of contents

Nomenclature

Symbol/Acronym	Definition
AIMS	Australian Institute of Marine Science
AODN	Australian Ocean Data Network
ARDC	Australia Data Research Commons
AusWaves	website with near real-time data of the IMOS Coastal Wave Buoys Facility
AWS S3	AWS Simple Storage Service
AWS	Amazon Web Services
DM	Delayed mode
GNSS	Global Navigation Satellite System
IMOS	Integrated Marine Observing System
IOOS	Integrated Ocean Observing System
IRDS	Institutional Research Data Storage
NCRIS	National Collaborative Research Infrastructure Strategy
NRT	Near real-time
QAQC	Quality assurance and quality control
QARTOD	IOOS Quality Assurance for Real Time Oceanographic Data
SARDI	South Australian Research and Development Institute
UWA	The University of Western Australia
H_{m0}	Sea surface wave spectral significant height
H_s	Significant wave height from time domain analysis
T_z	Wave period from time domain analysis
T_m	Sea surface wave spectral mean period
T_p	peak wave spectral period
D_m	Spectral sea surface wave mean direction
D_p	Spectral peak wave direction
σ_m	Spectral sea surface wave mean directional spread
σ_p	Spectral sea surface wave peak directional spread
SST	Sea surface temperature
P_{msl}	Barometric pressure
U_{wind}	Wind speed
θ_{wind}	Wind direction
E	1D Energy density
a_1, a_2, b_1, b_2	Fourier coefficients
f	Frequency
x	Sea surface east displacement

y	Sea surface north displacement
z	Sea surface east displacement
S_{zz}, S_{yy}, S_{xx}	Power Spectrum
C_{zx}, C_{zy}, C_{xy}	Cross spectrum
FFT	Fast Fourier Transform
t_w	Time length (in seconds) of each FFT segment
f_s	Frequency
D_z	Unwindowed displacement for each segment
D_{z_win}	Windowed displacements for each segment
D_{z_cor}	Variance corrected windowed displacements for each segment
Q_{zx}, Q_{zy}, Q_{xy}	Quadrature spectrum
$\bar{a}_1$, $\bar{b}_1$	Energy-weighted mean Fourier coefficients

1. Executive summary

Sustained, near real-time (NRT) observations of waves in coastal regions are an essential prerequisite to monitor, predict, and forecast coastal hazards that threaten coastal populations, infrastructure and marine operations. Additionally, NRT temperature observations in coastal regions are required to understand the impacts of environmental disturbances (both extreme events and long-term changes) on coastal ecosystems. To address this observational gap around Australia's coastline, the Integrated Marine Observing System (IMOS) created the Coastal Wave Buoy facility in 2024. As of December 2025, the wave buoy network consists of 23 sites situated at strategic, high-priority locations throughout Australia's coastal waters (10-70 m depths).

The IMOS Coastal Wave Buoy observation platform is the Sofar Spotter, a small-format GNSS (Global Navigation Satellite System) wave buoy with a temperature sensor embedded into the bottom of the hull. The Spotter collects GNSS data at 2.5 Hz and then performs on-board spectral analysis to produce timeseries of integrated and spectral wave parameters. Surface water temperature is collected at 1 Hz and averaged every minute on-board. The wave and temperature measurements are recorded locally on the buoy's internal memory card (delayed mode, DM), whereas summarised wave and temperature statistics (including spectral wave parameters) are transmitted to Sofar's cloud platform via cellular and/or satellite Iridium networks (near real-time, NRT).

This document outlines the data management and quality control steps that are used to post-process raw data collected by the wave buoys and to archive it on Australia's Ocean Data Network (AODN). The IMOS Coastal Wave Buoy facility supports both NRT and DM data streams, each of which undergoes quality control and assessment in accordance with best-practice guidelines outlined by the Integrated Ocean Observing System (IOOS) before being archived on AODN. To facilitate wider use of these data processing workflows by other organisations in Australia and globally, the IMOS Coastal Wave Buoy code repository is publicly available on GitHub.

2. Introduction

This document is the IMOS Coastal Wave Buoy Facility's recommended practice manual for near real-time (NRT) and delayed mode (DM) processing of surface wave and temperature data collected using Sofar Spotter wave buoys. The IMOS Coastal Wave Buoy facility consists of a central coordination facility (based at the University of Western Australia (UWA)) that is responsible for the overall facility coordination and data management, and four regional sub-facilities (South Australia, Victoria, New South Wales, and Queensland-Northern Territory) that comprise a number of regional operators who are responsible for the operational maintenance of the national observing sites (Figure 1a). There are currently 23 national sites (i.e., those directly supported by IMOS) around Australia's coastline, as well as an additional 35 sites that contribute data to the IMOS Coastal Wave Buoy facility from various regional partners (e.g., local governments, industry, university) (Figure 1b, Annex 8.1 - Table A1).

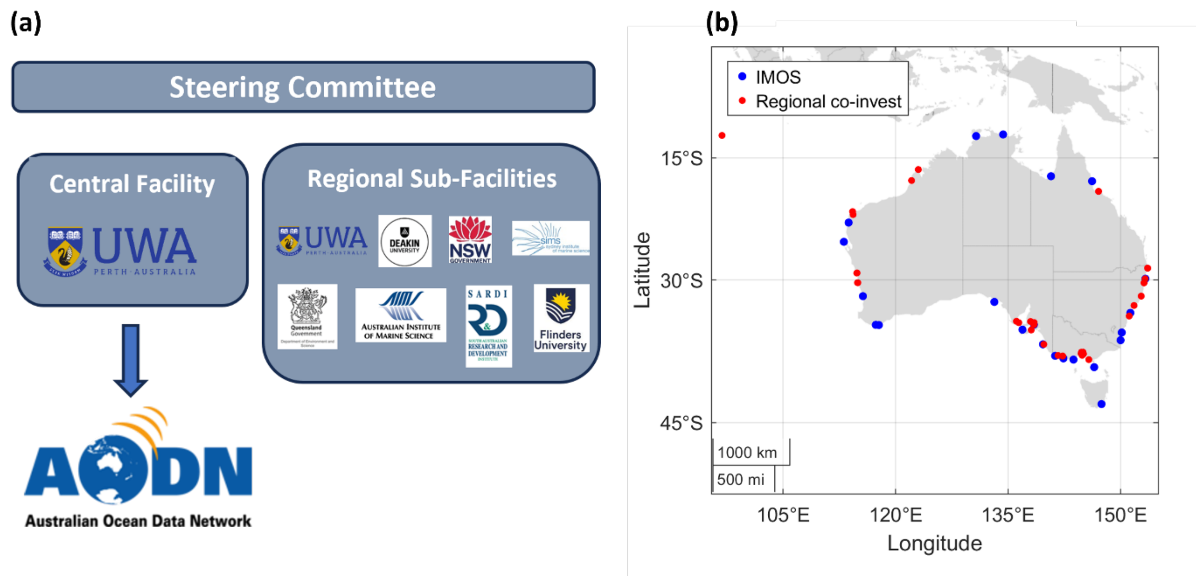

Figure 1. (a) Overview of the IMOS Coastal Wave Buoy facility organisational structure. (b) IMOS Coastal Wave Buoy network, including IMOS-supported sites (blue) and regional co-invested sites (red). Locations are representative of the network as of November 2025.

3. Background

Coastal wave observations are critical to a wide range of applications. Waves drive sediment transport, shape coastal landforms, and significantly influence the frequency and severity of hazards such as coastal erosion and inundation. Accurate and continuous observations of wave conditions are essential not only for monitoring and forecasting these hazards, but also for supporting a range of ecological, social, and economic functions. Coastal communities, infrastructure, marine industries, and natural ecosystems also all depend on the availability of high-quality wave data for informed decision-making and long-term adaptation planning (e.g., Freeman et al., 2017; Xie et al., 2023).

Australia's extensive coastline faces increasing threats due to rising sea levels and shifts in wave climates. However, the ability to monitor and predict these threats is often limited by the availability of in situ wave data, particularly in remote and regional areas where observational coverage has historically been sparse. Australia's publicly available in situ wave monitoring network historically consisted of approximately 35 sites that were distributed around the country and maintained independently by various state and federal agencies (Greenslade et al., 2018) (Figure 2). However, this network included significant spatial gaps and lacked national coordination in instrumentation standards, data formats, and data sharing protocols.

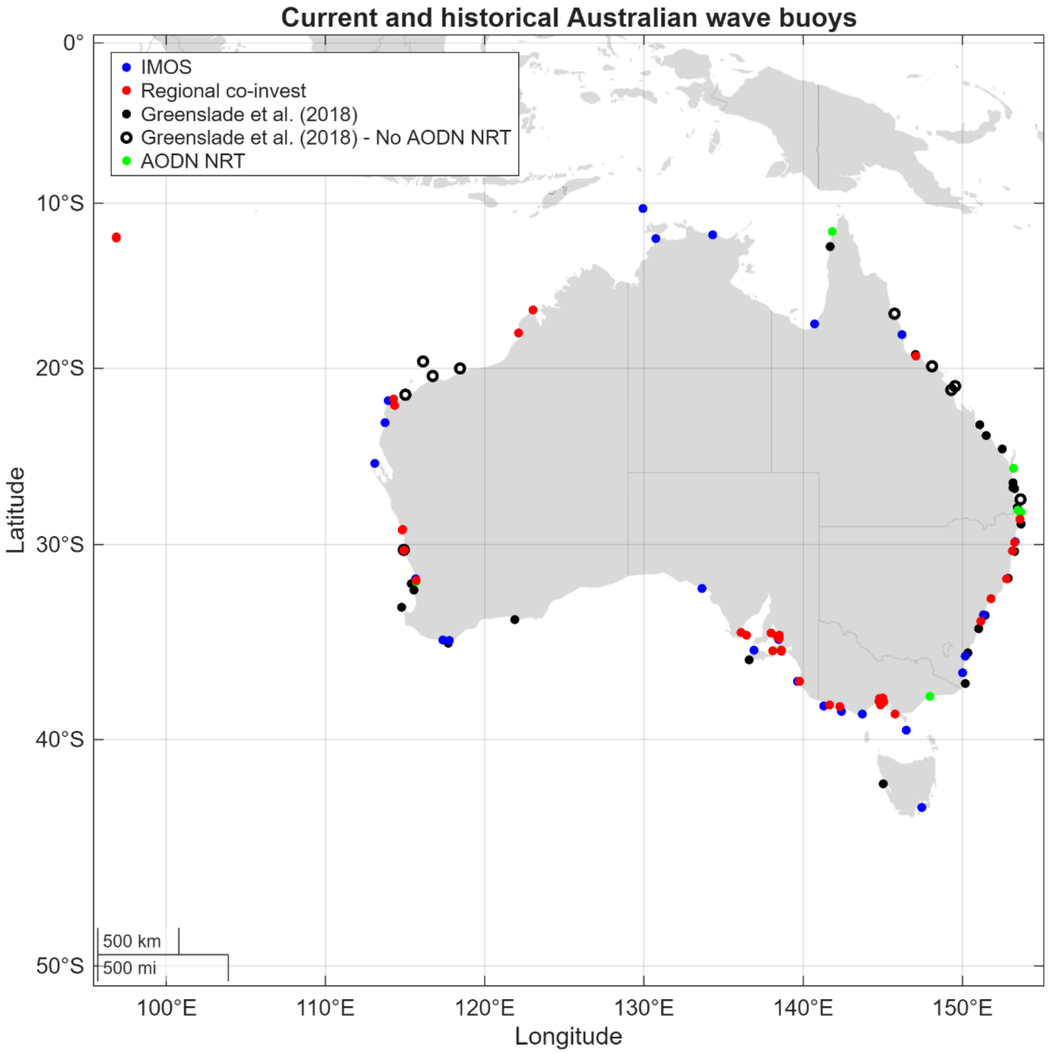

Figure 2. Integration of IMOS Coastal Wave Buoys with other Australian wave buoys. The IMOS Coastal Wave Buoy network is currently (as of December 2025) comprised of IMOS-support buoys (blue dots) and regional co-invested sites (red dots) – see Annex 8.1 for site details. Black dots represent the historical network of wave buoys outlined in Greenslade et al. (2018) at the time of its publication, with open black circles noting buoys from Greenslade et al., (2018) that no longer have real time data available on AODN. Green dots represent buoys additional wave buoys available in near real-time from AODN.

Recognizing these limitations, national science and infrastructure strategies (e.g., *Marine Nation 2025* and the *National Marine Science Plan 2015–2025*) identified the need for a comprehensive, integrated observing system that spans from the open ocean to the nearshore and littoral zones. A key research priority outlined in these plans was the expansion and standardization of Australia's in situ wave buoy network to enhance the nation's capacity for coastal monitoring and hazard prediction (Greenslade et al., 2023). The call for more observations was also matched by national support for the expansion of IMOS infrastructure into coastal and estuarine waters (Finkel, 2017) as well as development of a national wave data platform (IMOS' National Wave Archive for near real-time and delayed mode data) and standardisation of data sharing protocols (Berger & Galibert, 2023). These efforts culminated in the establishment of Australia's IMOS' Coastal Wave Buoy facility. The IMOS Coastal Wave Buoy facility comprises a nationally coordinated network of initially 23 coastal sites strategically positioned around Australia's coast (depths 10 - 70 m) to complement historical networks (Figure 2, Annex 8.1) and meet additional stakeholder priorities. These sites provide NRT and DM wave and surface temperature data to support research, operational services, and coastal planning.

In the following sections, we outline the instrument platform (Sofar Spotter) including details of the wave and temperature data collection and calibration and then provide the details of the data management (including QAQC) for both NRT and DM data streams.

4. Instrument platform and mooring

The facility platform is the 'Spotter' (Annex 8.2), a Global Navigation Satellite System (GNSS) wave buoy manufactured by Sofar Ocean Technologies. The Spotter has been extensively tested in diverse coastal environments across the globe (Collins et al., 2024; Raghukumar et al., 2019) including around Australia (Andrews & Peach, 2019; Hlophe et al., 2025). The core variables monitored by the IMOS Coastal Wave Buoys are surface waves and sea surface temperature. To measure these variables, the Spotter wave buoy is equipped with a GNSS motion unit for measuring waves and a Sofar temperature sensor for measuring sea surface temperature. The Spotter can also measure atmospheric pressure via a barometer installed in the hull and can provide estimates of wind speed and direction; however, these variables are not currently included in the facility's quality-controlled data streams (see Section 4.2 and Section 5.1).

4.1. Sensor specification, sampling and calibration

Wave buoys operate based on the principal assumption that the buoy freely follows the free surface of the ocean and thus, the buoy's movement reflects the water motions due to the waves. The Spotter GNSS motion unit (Annex 8.2) records its displacement in the horizontal and vertical coordinates at 2.5 Hz continuously while operating. The horizontal (east/north) displacements are derived from differencing the successive GNSS-derived positions. However, the vertical displacements are calculated by integrating the vertical velocity of the buoy derived from the Doppler shift of the GNSS satellite signals received by the buoy. In the vertical, this is a less noisy measurement than differencing the GNSS-derived vertical elevation. GNSS buoys (or devices in general) cannot be calibrated as the position uncertainty is a function of the satellite geometry at the time of measurement and activity within the ionosphere, which impacts the GNSS satellite signals as they travel to the Earth. Thus, no calibration is applied to the wave buoys used by the IMOS Coastal Wave Buoy facility. Houghton et al. (2021)

reported that Spotter's motion unit is able to measure wave displacements with an accuracy of +/- 0.02 m.

The Spotter is equipped with a Sofar temperature sensor that is embedded in the bottom of the hull (Annex 8.2). The sea surface temperature (SST) sensor samples (0.1 °C absolute accuracy, +/-0.02 °C resolution, -5 to 50 °C range) are continuously sampled at 1 Hz; however, 1 min averages are stored on the memory card, and different frequencies of observations are reported in NRT, depending on data mode (see below). IMOS Coastal Wave Buoy Spotters come with the factory calibration from Sofar. Currently (as of December 2025), no calibration is conducted, and the Spotter temperature sensors are quoted to have up to 0.1 °C/year of drift in absolute accuracy (Annex 8.2). However, IMOS Coastal Wave Buoy facility has built a system that is capable of performing the calibration protocols applied by Sofar, and this will be undertaken by the central facility in 2026. This document will be updated to reflect these updated protocols when they are complete.

4.2. Other sensors and measurements

The Spotter buoys are also equipped with a barometer (+/- 0.5mbar at 25 °C, range 700 to 1100 mbar; Annex 8.2) that is located behind one of the solar panels on the exterior of the hull. This instrument provides near real-time and delayed mode observations of air pressure; however, these observations have yet to be formally tested and validated in Australia. Therefore, these observations are stored on the central facility archives for completeness but are not available via AODN at this time.

Lastly, the Spotter provides estimates of wind speed and direction based on the shape of the high-frequency tail of the measured wave spectrum (Phillips, 1985; Thomson et al., 2013; Voermans et al., 2020). These observations are also stored on the central facility archives; however, they are not available via AODN as this is an inferred measurement based on the assumption that the high-frequency tail of the spectrum is in equilibrium with the current wind conditions, and validation of these measurements has yet to be rigorously conducted, particularly in coastal locations.

IMOS Coastal Wave Buoy facility is endeavouring to validate these observations (barometric pressure, wind speed and direction) around Australia and update QAQC protocols to enable the provision of these data via AODN in the future.

4.3. Mooring designs

All sensors (Sections 4.1 and 4.2) are integrated into the Spotter hull – there are no additional sensors attached along the mooring at this stage. The IMOS Coastal Wave Buoy facility uses either a single catenary (Figure 3a) or double catenary (Figure 3b) mooring. For all sites, the Spotter is connected to a surface float via the single or double catenary to ensure the buoy is able to freely follow the ocean surface. Generally, 8 mm polypropylene rope is used for the catenary and mainline; however, some regions have opted for using other materials for the catenary. Similarly, some sites require a larger surface float with an integrated light to adhere to navigational safety requirements.

Rigorous testing of different mooring designs and materials through the IMOS New Technology Proving project for low-cost wave buoys has demonstrated that these modifications have little impact on the final wave observations (Hansen et al., 2025). However, as part of a site's metadata, the IMOS Coastal Wave Buoy facility stores a copy of the mooring diagram for each deployment at each site (e.g., Figure 3) on local servers at UWA. The mooring diagrams are available on request from IMOS Coastal Wave Buoy facility.

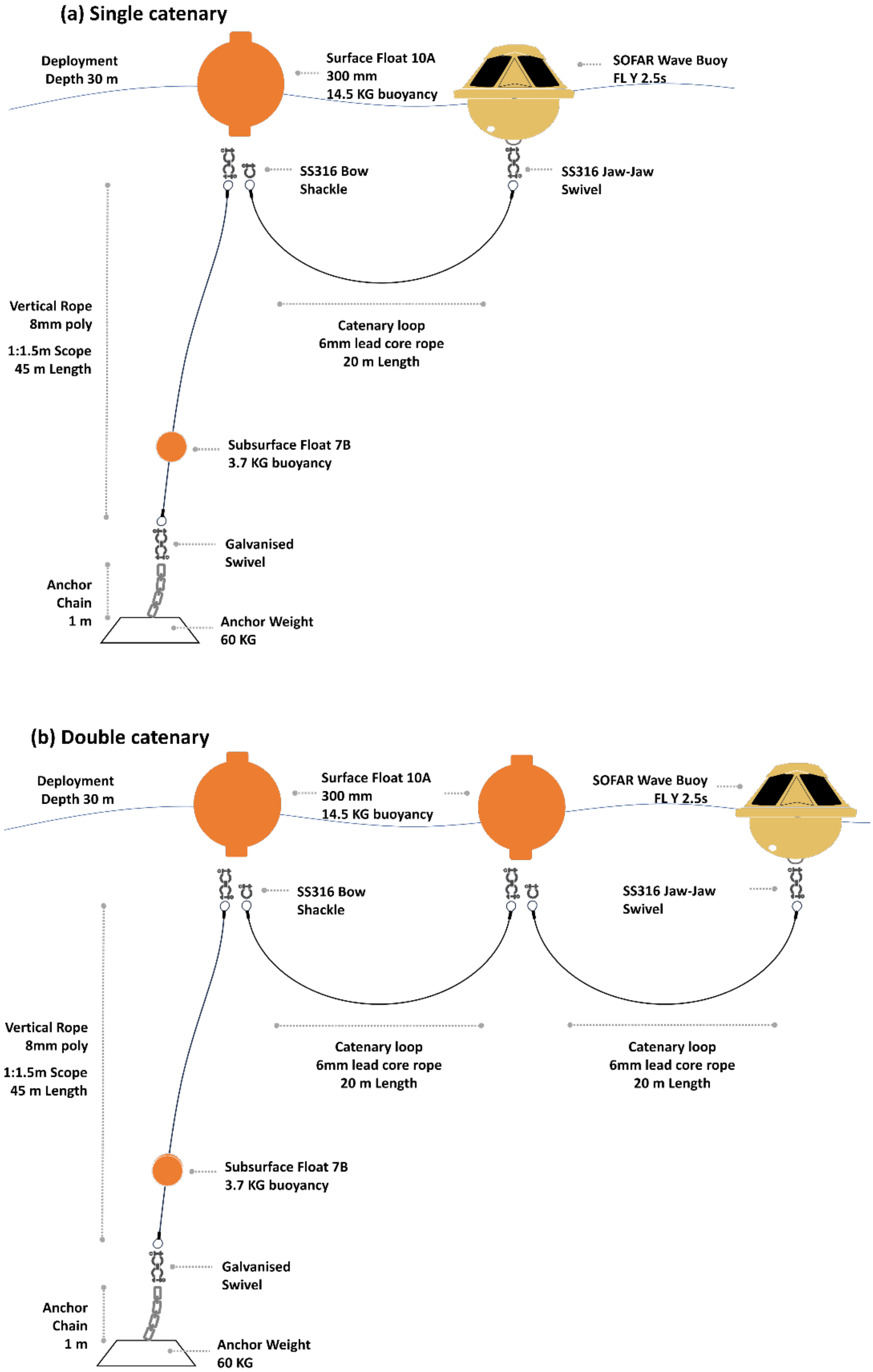

Figure 3. Example mooring diagrams using a (a) single catenary or (b) double catenary. Note, specific mooring details provided in (a) and (b) are specific to each site and are provided here to demonstrate the level of detail archived by IMOS Coastal Wave Buoy central facility.

5. Data management and data access

5.1. Observed parameters, data transmission, and data outlets

IMOS Coastal Wave Buoy facility collects, archives, and disseminates numerous wave variables as well as sea surface temperature in NRT and DM for both IMOS-supported and co-invested sites (Table 1). For NRT, data transmission occurs via cellular or satellite Iridium and depends on a given site's cellular coverage and availability. By default, Spotters prioritise cellular data transmission when available and then can 'fallback' to satellite transmission when required. IMOS Coastal Wave Buoy facility provides access to 'integrated wave parameter' and 'spectral wave parameter' in NRT and DM as well as the buoy's 'displacements' datasets in DM. Transmission type (cellular or satellite) determines the data that is transmitted to the Sofar API, and subsequently available to the IMOS Coastal Wave Buoy facility in NRT (Table 1; section 5.2.1). For DM data, following recovery of a buoy, the onboard memory card is post-processed following protocols outlined below (Section 5.2.2).

Data processing (in both NRT and DM) produces netCDF files that are formatted following the guidelines established in the Australian Research Data Commons project 'Catching Oz Waves' (Appendix 8.3; Berger & Galibert, 2023) and delivered to the AODN. AODN outlets include the National Wave Archive – Near Real Time and the National Wave Archive – Delayed mode as well as the IMOS THREDDS server. Data is also available in NRT via the IMOS Coastal Wave Buoy data platform, AusWaves. Note that the IMOS Coastal Wave Buoy data is delivered via AusWaves and undergoes the same quality control described below (Section 5.2.1), but it includes additional variables (without quality control) that are not provided to AODN (e.g., wind speed and direction). These data are not currently (as of December 2025) included in the AODN templates; however, IMOS Coastal Wave Buoy facility is endeavouring to undertake appropriate steps to include these data in both outlets in future.

Table 1. List of parameters measured by the IMOS Coastal Wave Buoy facility and co-invested sites in delayed mode and near real-time. Parameter names correspond to the 'long_name' in the netCDF templates (see Appendix 8.3). The netCDF file each parameter is stored in on AODN is included as well as the parameter's availability in near real-time and delayed mode.

Parameter	AODN netCDF	Available in delayed mode (DM)	Available in near real-time (NRT)
Sea surface wave spectral significant height (H_{m0})	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Sea surface wave spectral mean period (T_m)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Peak wave spectral period (T_p)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest

Spectral sea surface wave mean direction (D_m)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Spectral peak wave direction (D_p)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Spectral sea surface wave mean directional spread (σ_m)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Spectral sea surface wave peak directional spread (σ_p)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Sea surface temperature (SST)	Integrated parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest
Barometric pressure (P_{msl})	N/A	IMOS Coastal Wave Buoy + co-invest (on request)	N/A
Wind speed (U_{wind})	N/A	N/A	IMOS Coastal Wave Buoy + co-invest (via auswaves.org, no QAQC)
Wind direction (θ_{wind})	N/A	N/A	IMOS Coastal Wave Buoy + co-invest (via auswaves.org, no QAQC)
1D Energy density (E)	Spectral parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest (cellular only)
Fourier coefficients (a_1, a_2, b_1, b_2)	Spectral parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest (cellular only)
Frequency (Hz)	Spectral parameters	IMOS Coastal Wave Buoy + co-invest	IMOS Coastal Wave Buoy + co-invest (cellular)
Sea surface east displacement (x)	Displacements	IMOS Coastal Wave Buoy + co-invest	N/A
Sea surface north displacement (y)	Displacements	IMOS Coastal Wave Buoy + co-invest	N/A

Sea surface east displacement (z)	Displacements	IMOS Coastal Wave Buoy + co-invest	N/A

5.2. Data processing methods

Data processing and archiving occur for two streams: (1) NRT and (2) DM. Both NRT and DM post-processing involve quality assurance and quality control (QAQC) checks. Following suggestions in the Australian wave buoy operations best practice guidelines (Hansen and Kinsela, 2023), the IMOS Coastal Wave Buoy facility applies QAQC tests outlined in the IOOS Quality Assurance for Real Time Oceanographic Data (QARTOD) manual (U.S. Integrated Ocean Observing System, 2019), with an additional spike and watch circle test developed by IMOS Coastal Wave Buoy facility (Table 2). Specific steps in the NRT and DM data processing, including QAQC results (Table 3), are provided below; however, for both workflows, finalised netCDF files are uploaded to and available via the AODN.

Table 2. Description of QAQC tests used in data processing. Note, settings provided in the 'Example settings' are for demonstration only; in practice, these values are site-specific and determined via collaboration between the central facility and regional partners.

QAQC Test	Description	Example settings	Used in NRT processing	Used in DM processing
Mean and standard deviation (QARTOD - Test 15)	Checks if the data point is outside of the time series mean plus/minus standard deviation times a multiplier factor (N).	Parameter: H_{m0} N = 4	No	Yes
Flat line (QARTOD - Test 16)	Checks if the data point has the same value as a number of previous observations ($N_{suspect}$, N_{fail}) within a tolerance value (EPS).	Parameter: H_{m0} EPS = 0.025 m $N_{suspect}$ = 144 N_{fail} = 240	No	Yes
Max/Min/Acceptable Range (QARTOD - Test 19)	Checks if the data point value is outside of the maximum and minimum thresholds	Parameter: H_{m0} MIN = 0.1 m MAX = 10 m	Yes	Yes
Rate of change (QARTOD - Test 20)	Checks if the difference between two consecutive datapoints is greater than a defined threshold	Parameter: H_{m0} MAXDIFF = 2 m	Yes	Yes

Spike (IMOS Coastal Wave Buoy developed)	Checks if data is outside the difference between its previous and consecutive datapoints within a threshold.	Parameter: H_{m0} MAXDIFF = 2 m	No	Yes
Watch circle (IMOS Coastal Wave Buoy developed)	Checks buoy position (latitude/longitude) against the deployed location provided in metadata and a calculated watch circle area based on mooring configuration	SITELATITUDE = -38.75 ° SITELONGITUDE = 144.87 ° MAINLINE = 38 m CATENARY = 40 m STRECHFACTOR = 25% RESULTING WATCH CIRCLE = 137 m	Yes	Yes

Table 3. Possible QAQC flag values and meanings (adapted from U.S. Integrated Ocean Observing System, 2019). The quality control variable names found in the netCDF are also provided.

Quality control variable name	QC Flag Value	Meaning
WAVE_quality_control TEMP_quality_control	1 - Pass	Data have passed critical real-time QAQC tests and are deemed adequate for use as preliminary data.
	2 – Not evaluated	Data have not been QAQC-tested, or the information on quality is not available.
	3 – Suspect or of High interest	Data is considered to be either suspect or of high interest to operators and users. They are flagged as being suspect to draw further attention to them by operators.
	4 - Fail	Data is considered to have failed one or more critical real-time QAQC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
	9 – Missing Data	Data is missing; used as a placeholder

5.3. Near real-time (NRT) data management and QAQC

In NRT, Spotters can operate in a variety of data processing modes (e.g., standard, spectral, partition) and can transmit data via cellular and/or satellite networks. IMOS Coastal Wave Buoy national sites operate in 'spectral' mode (over both cellular and satellite transmission); in this configuration, integrated and spectral parameters (Table 1) are calculated over 60 min spectral windows and uploaded to the Sofar API every 60 min (one set of parameters per transmission). Regional co-invested sites typically operate in 'standard' mode, which provides integrated wave parameters calculated over a 30 min spectral window and uploaded to the Sofar API every 60 min (two sets of parameters per transmission). However, if a co-invested site is within cellular reception, then integrated and spectral parameters are able to be transmitted and are calculated over a 30 min spectral window (Table 1). The different spectral processing windows for IMOS Coastal Wave Buoys and regional co-invested sites is related to available Spotter data configurations for cellular and satellite transmissions and the need to maintain consistent spectral processing across both cellular and satellite transmission for a site (i.e., if a buoy loses cellular connectivity and reverts to satellite transmission). For example, the shortest spectral processing window for a Spotter operating in spectral mode over satellite data transmission in 60 min, however, for cellular data transmission, the processing window can be as short as 15 min. Therefore, to maintain consistent NRT data processing despite data transmission type, we set the processing window based on the satellite data transmission limits – for 'standard' mode, this is 30 min and for 'spectral' mode this is 60 min. For more information on the Spotter data modes, see Sofar's support documentation. The integrated and spectral parameters in NRT are calculated following general oceanographic conventions for wave data processing (Holthuijsen, 2007; Kuik et al., 1988), with full details outlined in Sofar's technical reference manual (Smit, 2024).

For sea surface temperature data, the number of observations transmitted per 60 min is determined by the transmission type (cellular or satellite). For sites using satellite networks, one temperature measurement is included with each data transmission (regardless of data processing mode) and is an average sample over the latest 10 seconds prior to upload. However, for cellular sites, 12 surface temperature observations (5 min averages) are included per hour.

For NRT data processing and QAQC, IMOS Coastal Wave Buoy facility accesses the data from each buoy via the Sofar API, performs QAQC following QARTOD standards (Table 2), formats monthly netCDF files that are provided to AODN, and formats daily CSV files that are uploaded to AusWaves (Figures 4 and 5). The general steps for NRT data processing involve (every hour):

1. Read site metadata (provided by regional operators, see Section 8.3).
2. Access Sofar API to retrieve new data
3. Combine new data with existing archived data
4. Run QAQC on the latest 24 hours of data each hour, so QAQC flags may get overwritten as new data becomes available. Specific tests include (Table 2):
    - QARTOD tests
        - Max/Min/Acceptable range (Test 19)

    - Rate of change (Test 20)
  - IMOS Coastal Wave Buoy Developed
    - Spike
    - Watch circle
5. Create/update daily CSV files for AusWaves
6. Create/update monthly netCDF files and upload to AODN

In NRT, QAQC is run on the integrated parameters (Table 1) and sea surface temperature. Each QAQC test is run independently on spectral significant wave height, peak wave period, peak wave direction, and surface temperature, and time points can be assigned a QC flag value of 1 to 9 (Table 3). QAQC results on each parameter are then compared, and a conservative approach is taken whereby the worst result across parameters and tests is used for the flag for a given time point. The NRT netCDF files contain variables that provide the QAQC results ('WAVE_quality_control' and 'TEMP_quality_control'), which can be used to filter the datasets for data that passes the QAQC protocols. Currently (as of December 2025), no QAQC is performed on the spectral parameters (i.e., energy density, a1, a2, etc.; Table 1), but this is planned to be implemented in the future.

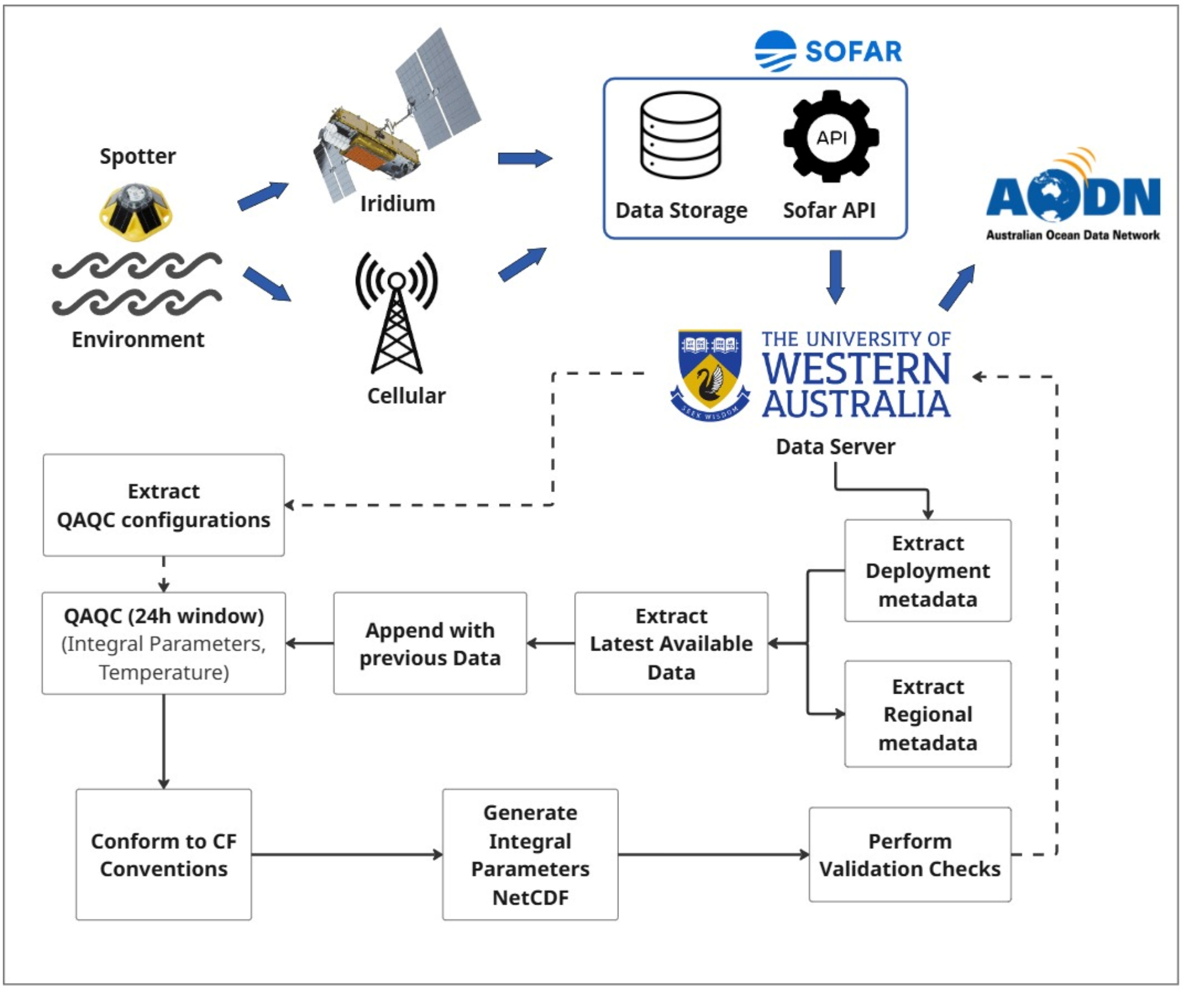

Figure 4. Overview of the real-time data pipeline for the IMOS coastal wave buoy facility.

5.4. Delayed-mode data processing and QAQC

Following wave buoy recovery, which occurs every 4 (Northern Territory sites only) or 6 months, the memory card data is transferred from the regional sub-facility team to the central facility for data processing (Figure 5). The raw data is stored internally at UWA and in an Amazon Web Services (AWS) S3 bucket.

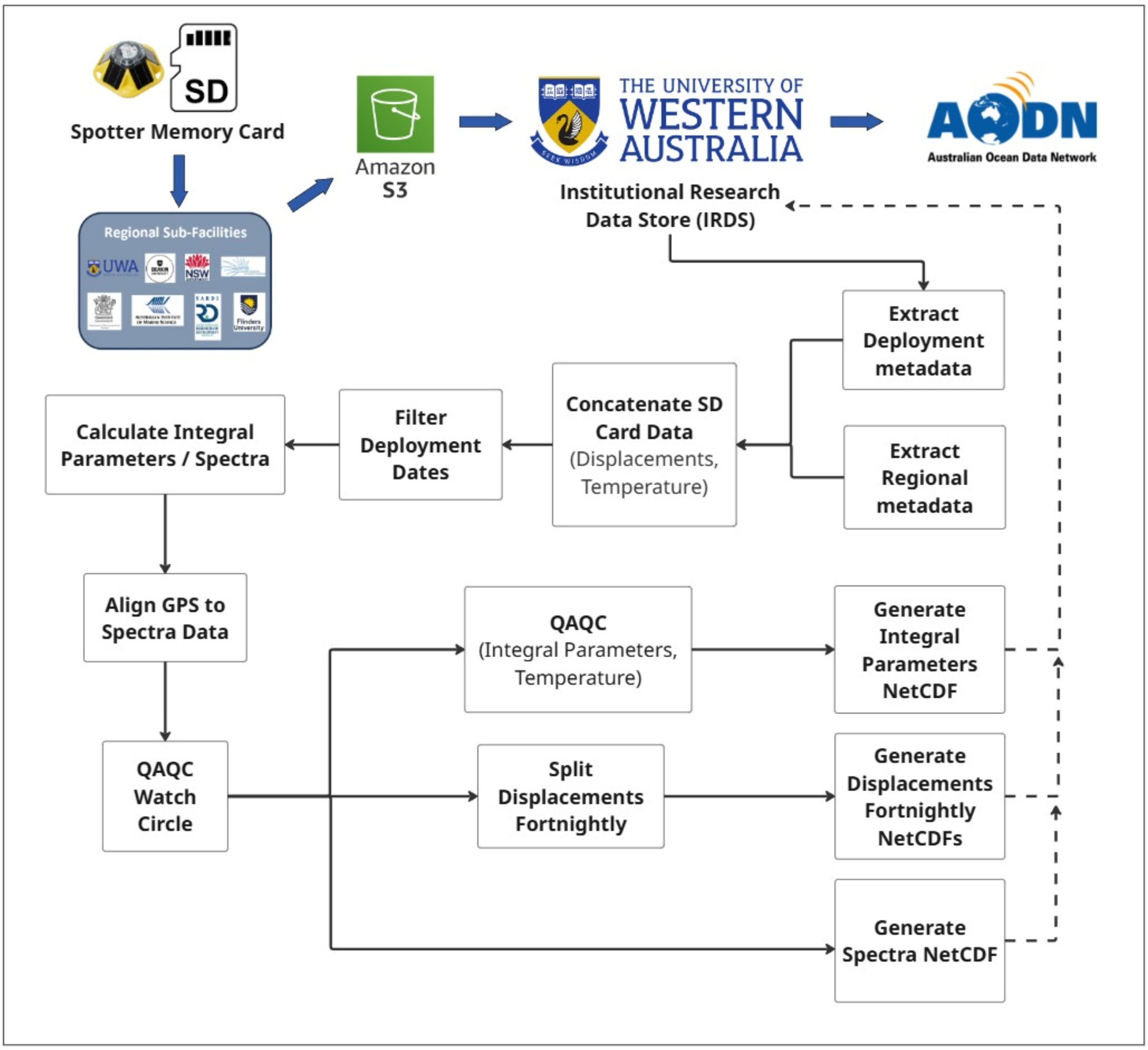

Figure 5. Overview of the delayed mode data workflow for the IMOS coastal wave buoy facility.

The raw memory card contains the raw wave buoy displacements (sampled at 2.5 Hz) as well as the sea surface temperature observations (1 min averages of the 1 Hz sampled data); these data form the basis of the post-processing workflows for the IMOS Coastal Wave Buoy facility. For sea surface temperature, the memory card data is directly QAQC'd, whereas for wave data, the displacement data undergoes further analysis.

The raw wave buoy displacements are organised into 30 min blocks for spectral analysis. For each 30 min block, raw displacements are divided into segments of 1024 samples, with each segment having 50% overlap. Prior to spectral analysis, an initial

QAQC step is conducted on each segment, whereby a zero-crossing analysis is used to calculate individual wave heights and periods, and these values are compared to the segment's significant wave height (H_s) and wave period (T_z). A segment failed our QAQC test if the segment contained one or more individual wave heights exceeding 2.25 times the H_s, or if one or more wave periods exceeded 4 times the T_z, or if one or more periods exceeded 30 s (Kurniawan et al., 2022). No effort is made to delete and/or replace flagged displacement values in each segment. Instead, if more than 1/3 of the segments for the complete 30 min record contained displacements that failed the QAQC test, that entire 30 min block was excluded from our analysis. If less than 1/3 of segments contained flagged displacement, the processing for that 30 min block was continued, but the segment(s) that contained the flagged displacements were excluded from the analysis. Following the displacements QAQC step, the spectral processing is completed following the details outlined in Annex 8.3 (Hansen et al., 2025) to produce integrated and spectral wave parameter datasets.

The integrated parameters and sea surface temperature undergoes QAQC following the QARTOD guidelines (Table 2), including a spike and watch circle test developed by IMOS Coastal Wave Buoy facility. Note, for sea surface temperature, there is currently (as of December 2025) no accounting for sensor drift (Section 4.1, Annex 8.2); however, this will be addressed in 2026 when buoys begin routine calibration by the central facility.

For DM data, the following tests are performed (Table 2):

- QARTOD tests
  - Mean and standard deviation (Test 15)
  - Flat line (Test 16)
  - Max/Min/Acceptable range (Test 19)
  - Rate of change (Test 20)
- IMOS Coastal Wave Buoy developed
  - Spike
  - Watch circle

QAQC tests are run on individual parameters and then pooled to assign a final QAQC flag for each time point. When assigning a final flag (Table 2), a conservative approach is taken whereby the worst QAQC test result is used. Importantly, no data is removed during this QAQC process; it is only flagged. QAQC settings for each test are varied as needed to account for site-specific details (e.g., max wave height, minimum temperature) and are archived at the central facility for each deployment. The DM netCDF files contain variables that provide the QAQC results ('WAVE_quality_control', 'TEMP_quality_control'), which can be used to filter the datasets for data that passes the QAQC protocols. Currently (as of November 2025), no QAQC is applied to the spectral data, but this is in development by the facility and will be included in the future.

6. Code repository

The facility maintains a GitHub code repository for both NRT and DM data processing workflows. Data processing workflows exist for both Python and MATLAB and are regularly maintained and updated by the IMOS Coastal Wave Buoy facility. The Python workflow is currently (November 2025) available on the code repository, with the MATLAB workflow to be included in 2026.

7. References

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8. Annexes

8.1. List of sites

Table A1. Sites comprising the IMOS Coastal Wave Buoy network. Depths were derived from the product AusBathyTopo (Australia) 250m 2024 (Beaman, 2024).

State	Site Name	Type	Latitude	Longitude	Depth
WA	Coral Bay	National	-23.1545	113.7369	27
	Shark Bay	National	-25.4945	113.1018	19
	Hillarys	National	-31.8513	115.6465	28
	Ocean Beach	National	-35.0490	117.3638	40
	Torbay West	National	-35.0687	117.7699	30
	Tantabiddi	National	-21.8936	113.9283	37
	Exmouth Gulf South	Co-invest	-22.1684	114.3382	7
	Exmouth Gulf North	Co-invest	-21.8002	114.2661	22
	Cygnet Bay	Co-invest	-16.5028	123.0341	11
	Cable Beach	Co-invest	-17.9005	122.1332	16
	Jurien Bay Inshore	Co-invest	-30.3150	114.9613	26
	Jurien Bay Offshore	Co-invest	-30.3156	114.9226	40
	Dongara Inshore	Co-invest	-29.1860	114.8625	19
	Dongara Offshore	Co-invest	-29.1980	114.8318	22
	Floreat	Co-invest	-31.9282	115.6812	20
	Cocos Islands North Entrance	Co-invest	-12.0878	96.8576	5
	Cocos Islands Lagoon	Co-invest	-12.1440	96.8658	15
SA	Brighton	National	-35.0250	138.4500	20
	North Kangaroo Island	National	-35.5700	136.9255	46
	Robe	National	-37.1443	139.6521	29
	Ceduna	National	-32.5056	133.1734	20
	West Beach	Co-invest	-34.9524	138.4833	5
	Semaphore	Co-invest	-34.8529	138.3518	21
	North Haven	Co-invest	-34.7980	138.4811	7
	Spilsby South	Co-invest	-34.8100	136.4300	40
	Black Point	Co-invest	-34.6800	138.0000	16
	Robe Guichen Bay	Co-invest	-37.1484	139.7701	9
	Victor Harbor Offshore	Co-invest	-35.6095	138.6323	30
	Victor Harbor Inshore	Co-invest	-35.5810	138.6189	12
	Boston Island	Co-invest	-34.6557	136.1168	24
	Cape Jervis	Co-invest	-35.6065	138.0853	15
VIC	Cape Bridgewater	National	-38.3599	141.2739	65
	Apollo Bay	National	-38.7538	143.7228	30
	Central	National	-38.0622	144.8672	23
	Wilsons Promontory	National	-39.5379	146.4834	74
	Bob	National	-38.6256	142.3831	64
	Dutton Way	Co-invest	-38.3205	141.6573	18
	Port Fairy	Co-invest	-38.3821	142.2872	26

	Sandringham	Co-invest	-37.9794	144.9932	13
VIC	Rosebud	Co-invest	-38.3021	144.8724	16
	Indented Head	Co-invest	-38.1361	144.7531	15
	Mt Eliza	Co-invest	-38.1630	145.0543	17
	Werribee	Co-invest	-37.9855	144.7752	11
	Inverloch	Co-invest	-38.7574	145.7664	49
TAS	Storm Bay	National	-43.2308	147.4589	43
NSW	Wooli	National	-29.8574	153.3139	29
	Collaroy Narrabeen	National	-33.7265	151.3068	15
	Bengello	National	-35.8800	150.1612	14
	Tathra	National	-36.7083	150.0010	30
	Cape Byron	Co-invest	-28.6274	153.6279	12
	Wooli Beach	Co-invest	-29.8692	153.2761	13
	Boambee Beach	Co-invest	-30.3356	153.1248	13
	Crowdy Head	Co-invest	-31.8492	152.7555	13
	Stockton	Co-invest	-32.9021	151.7987	13
	Port Hacking	Co-invest	-34.0787	151.1539	6
QLD	Karumba	National	-17.3547	140.7281	7
	Mission Beach	National	-17.9852	146.2040	22
NT	Fenton Patches	National	-12.1704	130.7348	26
	Maningrida	National	-11.9550	134.3094	14

8.2. Sofar Spotter sensor specification sheet

Below is the current (November 2025) IMOS Coastal Wave Buoy Spotter specification sheet retrieved from Sofar's support documentation.

Spotter Buoy • *Access Real-Time Surface Data*

A flexible and rapidly deployable metocean buoy that delivers real-time wave spectra, wind (derived), sea surface temperature, and atmospheric pressure data.

1. **Instant Data Access**
   View observations of waves & other surface variables in real time via dashboard and API to improve operational safety & efficiency.

2. **Scalable**
   Significantly lower total cost of ownership vs. traditional platforms. Easily deploy a network to maximize spatial density.

3. **Rugged & Reliable**
   Engineered to operate continuously in harsh marine conditions, from polar ice to extreme heat.

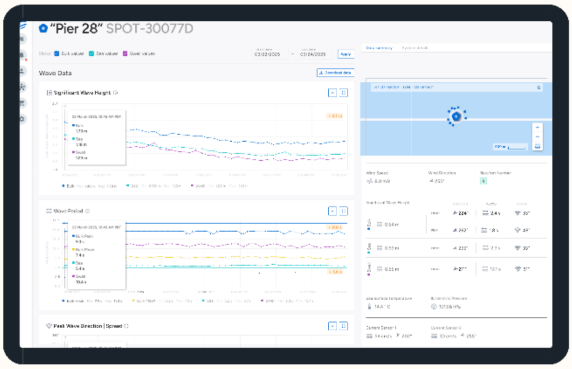
Spotter Measurements Wave & Wave Spectra — Wind (Derived) — Sea Surface Temperature — Atmospheric Pressure

User-Friendly Dashboard & API

View data sent in real time via satellite/cellular or download historical data stored in the cloud.

Remotely adjust settings and initiate over-the-air firmware updates with two-way communication to reduce downtime.

Leverage API to build custom dashboards that visualize forecast data and direct observations.



Trusted by USGS, IOOS Integrated Ocean Observing System, ONR, NOAA, 東京大学 The University of Tokyo, US Army Corps of Engineers

Core Specifications

Dimensions	Width: 42 cm (16 in), Height: 31 cm (12.2 in)
Weight	7.45 kg (16 lb 7 oz)
Connectivity	Satellite (Iridium SBD) and Cellular
Primary Power Source	Solar-powered, 5× 2 Watt, 6 Volt solar panels
Battery	Rechargeable lithium-ion 13,400 mAh capacity, 3.7 Volts

Motion Sensing

Motion Data Format	Easting (mm), northing, elevation, latitude, longitude
Wave Frequency Range	0.03 - 0.8Hz (30s - 1.25s)
Wave Direction Range	0 - 360°
Sampling Rate	2.5Hz
Wave Displacement Accuracy	Approximately ±2cm accuracy depends on field of view, weather conditions, and GPS system status

Data Outputs

	Standard Mode	Spectrum Mode	On Device
Significant Wave Height	●	●	●*
Peak Period	●	●	●*
Mean Period	●	●	●*
Peak Direction	●	●	●*
Mean Direction	●	●	●*
Peak Directional Spread	●	●	●*
Mean Directional Spread	●	●	●*
Variance Density Spectrum	○	●	●
Directional Moments (a1, b1, a2, b2)	○	●	●
3D Displacement Time Series @ 2.5 Hz (x,y,z)	○	○	●
Sea Surface Temperature	●**	●**	●**
Barometer	●	●	●
Wind Speed	●	●	○
Wind Direction	●	●	○
Drift Speed	○	○	●*
Drift Direction	○	○	●*
Geographical Coordinates (lat, lon)	●	●	●

Additional Onboard Sensors

Sea Surface Temperature (SST)

Accuracy	±0.1°C absolute
Resolution	±0.02°C
Range	-5°C - 50°C

Barometer

Accuracy	±0.5mbar at 25°C
Range	700 - 1100mbar

Data Storage

Onboard (SD Card)
Records time series of 3D displacement data, ships with 16GB SD card (supports up to 2TB, FAT32 format required)

Cloud Storage (Online Dashboard)
Online account includes real-time and historical data outputs, Spotter configurations, alerts, maps, and two-way communication

Misc. Specifications

System Monitoring
Battery voltage, solar panel power, internal humidity

Advised Mooring Depth
5 - 300m

Visibility Light
.5s flash every 2.5s (configurable), minimum 1 mile visibility in normal conditions

Firmware Updates
USB-C and over-the-air updates (cellular only)

Usability
Physical on/off switch, run/idle magnetic toggle, user LEDs and integrated grab handles

*Can derive from SD card data
**Sea Surface Temperature is not available with Smart Mooring

8.3. Displacement-based spectral processing methods

Following the initial QC step that is conducted on the raw displacements used in each 30 min block for analysis (see Section 5.2.2), the spectral processing is completed similar to the method outlined in Thomson et al (2018). First, a Hann window is applied to each segment of the heave, north, and east displacement time series. The windowed segments are then rescaled to preserve the variance, following:

$$D_{z\_cor} = D_{z\_win}\sqrt{\frac{var(D_z)}{var(D_{z\_win})}}, \quad (1)$$

where D_{z_cor} are the variance-corrected windowed displacements for each segment, with the subscript *z* indicating heave, D_{z_win} the windowed displacements for each segment, D_z the unwindowed displacement for each segment, and the var( ) indicating the variance over the segment. The same is also computed for the north (*y*) and east (*x*) components.

Following the variance correction, a two-sided Fast Fourier Transform (FFT) is completed on each segment. The second half of each FFT is deleted to make it one-sided, the first coefficient (mean) is removed, and a final coefficient is added with a value of 1×10^{-10}m² to maintain the length of the FFT. A value of 1×10^{-10}m² is used rather than zero to avoid NaNs later in the processing. The power (*S*) and cross (*C*) spectra are then computed as:

$$S_{zz}(f) = \frac{2F_z(f)F_z^*(f)}{t_w f_s}, \quad S_{xx}(f) = \frac{2F_x(f)F_x^*(f)}{t_w f_s}, \quad S_{yy}(f) = \frac{2F_y(f)F_y^*(f)}{t_w f_s}, \quad (2)$$

$$C_{zx}(f) = \frac{2F_z(f)F_x^*(f)}{t_w f_s}, \quad C_{zy}(f) = \frac{2F_z(f)F_y^*(f)}{t_w f_s}, \quad C_{xy}(f) = \frac{2F_x(f)F_y^*(f)}{t_w f_s}. \quad (3)$$

where *F* indicates the one-sided output of the FFT (the subscripts denote the displacement coordinate), * the complex conjugate, t_w the time length (in seconds) of each FFT segment, and f_s the sample frequency. In equations (2) and (3), the (*f*) indicates the variable is a function of frequency; however, for simplicity, this notation is omitted in subsequent equations. The two in the numerator in (2) and (3) is to restore the total variance, as one side of the FFT was excluded. To smooth the spectrum and increase the statistical confidence of each frequency bin, the power and cross-spectrum are merged across frequency space by averaging the three adjacent frequency bins. Following merging, an ensemble average is produced by averaging the power and cross-spectrum in each merged frequency bin across all segments. The quadrature spectrum (Q_{zx}, Q_{zy}, and Q_{xy}) is then calculated as the imaginary component of the cross-spectrum. Using the quadrature spectrum, the lowest four Fourier coefficients are calculated as:

$$a_1 = \frac{Q_{zx}}{\sqrt{S_{zz}(S_{xx}+S_{yy})}}, \quad b_1 = \frac{Q_{zy}}{\sqrt{S_{zz}(S_{xx}+S_{yy})}}, \quad (4)$$

$$a_2 = \frac{(S_{xx}-S_{yy})}{(S_{xx}+S_{yy})}, \quad b_2 = \frac{2real(S_{xy})}{(S_{xx}+S_{yy})}. \quad (5)$$

where *real( )* indicates the real component of the cross-spectrum.

From the power spectrum, we calculate the spectral significant wave height (H_{m0}) as

$$H_{m0} = 4\sqrt{\int_{f_1}^{f_2} S_{zz} df} \qquad (6)$$

where f_1 and f_2 indicate the start and end frequencies of the integration, and df is the frequency resolution. The mean period (T_m) is calculated as:

$$T_m = \sqrt{\frac{\int_{f_1}^{f_2} S_{zz} f^0 df}{\int_{f_1}^{f_2} S_{zz} f^1 df}}. \qquad (7)$$

The mean direction (*Dm*) and spreading (σ_Θ) for each frequency are calculated using the Fourier coefficients following:

$$D_m = 270 - \frac{180}{\pi} tan_2^{-1}\left(\frac{b_1}{a_1}\right), \qquad \sigma_\theta = \frac{180}{\pi}\sqrt{2(1 - [a_1{}^2 + b_1)^2]^{1/2})}, \qquad (8)$$

where $tan_2^{-1}()$ is the four-quadrant inverse tangent (i.e., atan2) and 270 is used to convert the directions to nautical convention. Similarly, the mean direction and spreading across a range of frequencies is calculated as:

$$\overline{D}_m = 270 - \frac{180}{\pi} tan_2^{-1}\left(\frac{\overline{b}_1}{\overline{a}_1}\right), \qquad \overline{\sigma}_\theta = \frac{180}{\pi}\sqrt{2(1 - [\overline{a}_1{}^2 + \overline{b}_1{}^2]^{1/2})}, \qquad (9)$$

where $\overline{a}_1$ and $\overline{b}_1$ are the energy-weighted mean Fourier coefficients,

$$\overline{a}_1 = \frac{\int_{f_1}^{f_2} a_1 S_{zz} df}{\left(\int_{f_1}^{f_2} S_{zz} df\right)}, \qquad \overline{b}_1 = \frac{\int_{f_1}^{f_2} b_1 S_{zz} df}{\left(\int_{f_1}^{f_2} S_{zz} df\right)}. \qquad (10)$$

8.4. netCDF and metadata templates

The IMOS Coastal Wave Buoy metadata templates and netCDF standards were established as part of the "Catching Oz Waves" project that was led by IMOS' AODN and was funded by the Australia Data Research Commons (ARDC) (Berger & Galibert, 2023). This project brought together organisations from around Australia who are actively collecting wave data to decide on the essential variables and metadata required for a standardised approach to archiving wave data in Australia. These standards are currently being utilised for archiving NRT and DM data for the IMOS Coastal Wave Buoy facility. In NRT we are archiving integrated and spectral parameters, and in DM we also archive raw displacement data. The netCDF templates are maintained as part of the IMOS Coastal Wave Buoy Github repository.