An Evaluation of Current and Emerging In-situ Ocean Wave Monitoring Technology

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Abstract
Historically the offshore ocean wave-monitoring field has been dominated by surface following wave buoys utilising accelerometers. However, recent advancements in technology have introduced alternate global positioning system (GPS) sensors. To monitor wave conditions effectively, it is important to have a comprehensive understanding of available wave monitoring devices. A three-month field trial was undertaken at the Gold Coast, Queensland, deploying nine wave monitoring devices for comparison to Datawell's DWR-MkIII, which is considered the industry standard. Devices used in this study include four GPS buoys, one accelerometer buoy, two pressure transducers and two prototype devices. For each device, wave parameters were either examined, as the on-board calculated parameters, or by using manufacturer provided post-processing software. In addition, parameters were recalculated from the raw displacements to reduce variability caused by different calculation methods.

The comparison shows excellent agreement for significant wave height (Hs) and maximum wave height (Hmax) across all commercially available devices in both the on-board and recalculated parameters. Peak period (Tp) returned the weakest agreement across all devices compared to the DWR-MkIII, most likely due to the presence of bi-modal sea-states, differing spectral calculation methods and GPS signal loss. Two GPS buoys developed by Spoondrift Technologies Inc. sustained damage, with one resulting in device failure after two months. The SCRIPPS GPS prototype device compared well to the DWR-MkIII across all parameters; however, suffered antenna damage resulting in loss of satellite connection. The prototype smartphone app had issues with low-frequency interference and the pressure transducers displayed poor agreement in wave period, potentially due to considerably shorter recording period and fouling.

The recalculated parameters from the GPS equipment demonstrated that appropriate filtering can help overcome GPS loss issues, indicating that smaller GPS based devices may be an appropriate alternative in future wave monitoring applications. However, further consideration of their robustness during extreme events may be warranted.

Keywords: wave measurements, comparison, buoy, prototype device.

1. Introduction
Long-term wave monitoring is crucial to understanding coastal processes that influence human activity in the coastal zone. Despite the usage of long-term wave datasets across multiple disciplines, global monitoring networks are still widely underdeveloped. Multiple devices have been designed to monitor wave parameters, the most notable being: wave monitoring buoys (directional and non-directional); Acoustic Doppler Current Profilers (ADCP); high-frequency radars; and pressure transducers. Unfortunately these devices are expensive or require costly infrastructure to deploy, thus setting up extensive monitoring networks is often not economically viable. To reduce the cost of wave monitoring programs, new low-cost alternatives are being developed; however, they are often relatively untested in open ocean environments. The introduction of alternative global positioning system (GPS) based sensors is foremost amongst these inexpensive alternatives, primarily due to the absence of mechanical accelerometers that are predominantly used in wave buoys, thereby, resulting in reduced equipment size, easier deployments, reduced sensitivity, and the need for calibration [10] [12] [14].

Whilst the application of GPS technology in ocean monitoring is becoming widespread, few emergent devices have undergone lengthy sea trials for comparison to the widely used and tested accelerometer buoys.

The primary objective of this trial is to test emerging cost-effective technologies by comparing the parameter outputs of in-situ wave measurements collected over a three-month period. While there is no clearly defined industry standard for wave monitoring, Datawell products – specifically accelerometer-based sensors – are arguably the most commonly used buoys [13], successfully being applied in wave measurement applications for many years [9]. Datawell buoys have undergone multiple comparison and validation field studies, and thus are considered as the best available reference/standard in wave monitoring technology [17]. As such, it is essential that the performance of new measuring methods and equipment align with the extensively tested and efficient technology offered by Datawell’s 50+ years of experience [15].

2. Site Location and Set-up
This study was conducted offshore of the Gold Coast in South East Queensland, Australia. The site
is a long-term wave monitoring site for the Coastal Impacts Unit (CIU), Department of Environment and Science, and has been active since 21 March 1987 [11]. Nine devices were deployed for comparison with Datawells DWR-MkIII (Table 1), including seven directional wave measuring devices consisting of five buoys and two prototype devices. Two non-directional pressure transducers were also deployed. The estimated water depth at the deployment site is ~16 m, and the Datawell DWR-MkIII was located at 27° 57.876’ S, 153° 26.500’ E. Historical wave climate data indicates that the average significant wave height ($H_s$) is 1.12 m, with a dominant east to east-southeast wave direction [11]. The monthly average significant wave height ($H_s$) varies throughout the year, peaking at 1.37 m in March to 0.94 m in September, with a modal height of about 0.9 m. The top five maximum recorded wave heights ($H_{max}$) range from 10.6 to 12.0 metres. Peak wave periods ($T_p$) typically range from 3 to 15 seconds, with a unimodal period of about 10 seconds. Occasional bimodal sea states can be apparent, particularly in cyclone season.

Table 1 Equipment specifications

<table>
<thead>
<tr>
<th>Device</th>
<th>Measurement Principle</th>
<th>Record Interval (min)</th>
<th>Data frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR-MkIII</td>
<td>Accelerometer</td>
<td>26.6</td>
<td>1.28</td>
</tr>
<tr>
<td>DWR-G4 x2</td>
<td>GPS</td>
<td>26.6</td>
<td>1.28</td>
</tr>
<tr>
<td>TriAxys</td>
<td>Accelerometer</td>
<td>20.0</td>
<td>1.28</td>
</tr>
<tr>
<td>Spoondrift Spotter x2</td>
<td>GPS</td>
<td>30.0</td>
<td>2.5</td>
</tr>
<tr>
<td>RBRRedet</td>
<td>Pressure</td>
<td>8.5</td>
<td>4</td>
</tr>
<tr>
<td>Aanderaa</td>
<td>Pressure</td>
<td>8.5</td>
<td>4</td>
</tr>
<tr>
<td>SCRIPPS DWSD</td>
<td>GPS</td>
<td>≈17.0</td>
<td>4</td>
</tr>
<tr>
<td>WaveApp</td>
<td>Accelerometer</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Due to the dominant easterly wave direction indicated by historical climate data, equipment was deployed parallel to the shore along a contour line for uniform depth during February 2018, enabling the instrumentation to capture comparable data from the same wave train. Devices were deployed approximately 150 metres apart in order to prevent mooring system entanglement and the RBR and Aanderaa pressure transducers were bottom mounted together in a weighted triangular frame ~1 m above the seafloor, with a float as a marker.

2.1 Mooring Configurations

Manufacturer recommended mooring designs were followed as closely as possible for all wave buoys [2] [9] [18], however, minor alterations were made to the DWR-MkIII and TriAxys mooring configurations. Alterations were based on technical advice from personnel at CIU, founded on over 40 years of wave monitoring experience, and primarily consisted of changes to the anchoring method, and have been utilised in numerous deployments with no negative influence on the buoy. Both the DWR-MkIII and the TriAxys buoy incorporate a rubber cord which, due to the added elasticity enables greater flexibility and range of motion when following the orbital motion of ocean water particles [7] [9].

3. Analysis Techniques

All commercially available instruments provide an automatic wave summary output, either calculated on the device or by post processing software. As these automatic outputs are what typical users will be relying on for wave measurements it is important to examine how they compare to the DWR-MkIII. Parameters compared were $H_s$, $H_{max}$, $T_p$, and average period ($T_2$). Whilst each device provides most of these parameters, there are some variations in calculation methods. These discrepancies introduce undesired variability and are a key limitation in making direct comparisons between each device. As such, in order to rule out differences in calculation methods, non-directional parameters have also been recalculated from devices that also provide raw displacements, enabling a more consistent comparison of each devices ability to measure the motion of waves. Recalculated statistics are unavailable for the Aanderaa and the RBR as they were not set up to record raw displacement data.

Filtering methods were also incorporated into the recalculation of wave parameters in order to validate the data and remove errors. This allowed various errors in records to be identified in the devices where possible. The re-calculation process was adapted from validation procedures developed by the CIU, aimed at ensuring quality and integrity of its long-term historical data sets. This process is implemented in four stages: 1) a coarse spike removal filter is applied in order to remove large spikes exceeding five times the standard deviation; 2) a Butterworth high pass filter is applied to frequencies lower than 0.025 Hz, or periods longer than 40 seconds; 3) wave statistics are recalculated using similar methods to those outlined by Datawell [9]; and 4) range and ratio checks that are used to identify potential erroneous records for review [5].

In order to analyse the vast amount of data produced from the nine wave monitoring devices, a number of statistical parameters were chosen to compare the test devices to the DWR-MkIII. Including Spearman’s correlation coefficient (1), RMSE, bias (2), and Scatter Index (3).

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}}$$  

(1)
\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - y_i)^2} \]  
\[ BI = \bar{x} - \bar{y} \]

Where \( x \) is the test device, \( y \) is the DWR-MkIII, and \( N \) is the number of data pairs. The \( r \) values provided are calculated using the non-parametric Spearman’s correlation test, as not all variables were normally distributed as assessed by the Shapiro–Wilko test. Due to the nature of this analysis, a comparison can only be undertaken when there are simultaneous records from each wave measurement system and the DWR-MkIII. Statistical analysis has been undertaken for both automatic summaries provided directly from each device and recalculated statistics.

### 4. Results and Discussion

For the purpose of this paper, where multiple devices of the same model (i.e. Spotter’s and DWR-G4’s) were used, only one device has been examined. Additionally, due to device malfunction (Spotter) and battery limitations (DWR-G4) data for these devices was only available for the first two months of the trial. Over the trial period, \( H_s \) varied between 0.4 (99 per cent exceedance) to 3.0 m (1 per cent exceedance), with \( H_{max} \) reaching up to 5.5 m in June. \( T_p \) ranged between 5 and 15 seconds and a bimodal sea state was evident in April. Time series of parameters \( H_s, H_{max}, T_p \), and \( T_z \) produced by the DWR-MkIII (automatic outputs) are provided in Figure 1 demonstrating the wave climate for the duration of the trial.

![Figure 1](image.png)

Figure 1 Number of devices deployed for the comparison trial (top), and time series of wave parameters \((H_s, H_{max}, T_p, T_z)\) produced by the DWR-MkIII (automatic output) for the duration of the trial.

#### 4.1 Automatic Outputs

The following sections compare the DWR-MkIII against other commercially available instruments based on wave parameters, as calculated on-board each instrument. Statistical test results are provided in Table 2 and Table 3 and scatter plots are provided in Figure 2 and Figure 3. No further validation or reanalysis was undertaken. Analysis was undertaken for the prototype devices (as outlined in Table 1) independently of the commercially available devices in section 4.3.

##### 4.1.1 Wave buoys

The Spoondrift Spotter has a highly correlated \( H_s \), however does not record \( H_{max} \) which is a limitation for some applications. Moderate correlation was shown for \( T_p \), while \( T_z \) displays a strong correlation there is a notable positive bias in comparison to the DWR-MkIII, which can be attributed to differing calculation methods (Table 2 and Figure 2). The Datawell DWR-G4 strongly correlated for \( H_s \), however displayed a positive bias consistently measuring higher than the DWR-MkIII. Additionally while the DWR-G4’s \( H_{max} \) values generally aligned and displayed good agreement with the DWR-MkIII a number of values were overestimated by up to two metres difference (Figure 2). \( T_s \) also displayed a number of inflated values and consequently a weaker correlation. \( T_z \) displayed a higher correlation than \( T_p \) for the DWR-G4.

<table>
<thead>
<tr>
<th>Device</th>
<th>Method</th>
<th>( H_s ) (m)</th>
<th>( H_{max} ) (m)</th>
<th>( T_p ) (s)</th>
<th>( T_z ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spotter</td>
<td>( r )</td>
<td>0.99</td>
<td>-</td>
<td>0.65</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>( RMSE )</td>
<td>0.1</td>
<td>-</td>
<td>2.12</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>( BI )</td>
<td>-0.05</td>
<td>-</td>
<td>0.55</td>
<td>0.79</td>
</tr>
<tr>
<td>DWR-G4</td>
<td>( r )</td>
<td>0.98</td>
<td>0.92</td>
<td>0.60</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>( RMSE )</td>
<td>0.18</td>
<td>0.45</td>
<td>6.36</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>( BI )</td>
<td>0.13</td>
<td>0.06</td>
<td>1.27</td>
<td>0.23</td>
</tr>
<tr>
<td>TriAxys</td>
<td>( r )</td>
<td>0.98</td>
<td>0.92</td>
<td>0.61</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>( RMSE )</td>
<td>0.08</td>
<td>0.31</td>
<td>2.16</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>( BI )</td>
<td>0.02</td>
<td>-0.04</td>
<td>0.5</td>
<td>-0.18</td>
</tr>
</tbody>
</table>
4.2 Recalculated parameters

Results from recalculated wave parameters enable a ‘like-for-like’ comparison between each wave monitoring device and the DWR-MkIII. \( H_s \), \( H_{\text{max}} \), and \( T_z \) all displayed a reasonably high correlation in comparison with the DWR-MkIII across all wave buoys (Table 4 and Figure 4). As with the comparison of automatic summaries discussed previously, \( T_p \) had a relatively low correlation with the DWR-MkIII across all buoys, likely due to the variability introduced by a bimodal sea state. Comparison of the recalculated \( H_s \) from the wave buoys showed a minimal increase in correlation to the DWR-MkIII, compared to parameters from each device’s automatic output. With the recalculated parameters the Spotters \( H_{\text{max}} \) is shown to have a strong correlation to the DWR-MkIII. This parameter was not provided in the automatic output for the Spotter. The DWR-G4 and the TriAxys have a slightly weaker recalculated \( H_{\text{max}} \) correlation;

Table 4 Statistical tests for the recalculated parameters of the wave buoys compared to the DWR-MkIII

<table>
<thead>
<tr>
<th>Device</th>
<th>Method</th>
<th>( H_s ) (m)</th>
<th>( H_{\text{max}} ) (m)</th>
<th>( T_p ) (s)</th>
<th>( T_z ) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spotter</td>
<td>( r )</td>
<td>0.99</td>
<td>0.92</td>
<td>0.69</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.08</td>
<td>0.33</td>
<td>1.81</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>BI</td>
<td>0.06</td>
<td>0.14</td>
<td>0.19</td>
<td>0.04</td>
</tr>
<tr>
<td>DWR-G4</td>
<td>( r )</td>
<td>0.99</td>
<td>0.91</td>
<td>0.70</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.07</td>
<td>0.38</td>
<td>1.68</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>BI</td>
<td>0.05</td>
<td>0.17</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td>TriAxys</td>
<td>( r )</td>
<td>0.98</td>
<td>0.91</td>
<td>0.59</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.09</td>
<td>0.98</td>
<td>2.15</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>BI</td>
<td>0.06</td>
<td>0.16</td>
<td>0.22</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 3 Automatic outputs (\( H_s \), \( H_{\text{max}} \), \( T_p \), \( T_z \)) for the pressure transducers compared to the DWR-MkIII with a 1:1 line.

4.1.2 Pressure Transducers

The pressure transducers displayed a strong correlation for \( H_s \), however, the RBR seemed to consistently underestimate \( H_s \). The Aanderaa displayed a strong correlation with \( H_{\text{max}} \), while the RBR’s correlation was slightly weaker. Both the Aanderaa and the RBR had a poor correlation to the DWR-MkIII for \( T_p \) as well as \( T_z \), which also had a notable positive bias (Table 3 and Error! Reference source not found.). The difference in sampling frequency between the pressure transducers and the DWR-MkIII, the shorter wave record (8.5 min in comparison to 26.6 min), and attenuation due to depth limitations are likely major contributing factors for the poor agreement between \( T_p \) and \( T_z \). The Aanderaa is suitable for deployments up to 15 m, and the RBR 20 m.
4.3 Prototype Devices

4.3.1 SCRIPPS DWSD

The prototype Directional Wave Spectra Drifter (DWSD) GPS device developed by SCRIPPS [6] was unable to attain satellite connection throughout the trial period, however, it was functional for an earlier two-month deployment in August and September 2017. Throughout this period, wave parameters from the SCRIPPS DWSD compared to the DWR-MkIII displayed general consistency, with $H_s$ and $T_p$ showing very little bias, while a comparison of the Scripps $T_z$ with the DWR-MkIII showed slight positive bias. Although a general uniformity between the devices was attained, as is displayed through time series comparisons (Figure 5). However, difficulties connecting to the satellite system were evident throughout the dataset, resulting in a sporadic time series which made determining a direct correlation between wave records challenging.

However, other testing mechanisms improved such as the RSME. Recalculated $T_p$ had large differences for the DWR-G4 in comparison to the automatic data outputs and shows significant improvements in goodness of fit measurements. This improvement is due to the application of filters (outlined in Section 3), in addition to the removal of wave records that were deemed irreparably corrupt. Mostly due to GPS signal loss creating an error in the raw displacements discussed at length in Section 4.4. $T_z$ from the DWR-G4 shows similar improvement. While the correlation of recalculated $T_z$ for the Spotter shows no improvement in correlation compared to the DWR-MkIII, the positive bias that was present in Error! Reference source not found. is now absent; this absence suggests that $T_z$ was previously affected by a differing calculation method.

4.3.2 WaveApp

A smartphone based WaveApp [16] was deployed inside the hull of DWR-G4 in order to enable an inter-sensor comparison of data. Throughout the deployment the DWR-G4 experienced a corrupted GPS signal which heavily impacted the wave period recorded ($T_p$ and $T_z$), possibly caused by mooring forces. The examination of the raw accelerations recorded by the WaveApp showed significant low-frequency noise occurring between 8 and 15 seconds. In order to filter the raw signal to produce heave displacements that were not heavily affected, a frequency filter was applied to the acceleration signal a frequency filter was applied to the acceleration signal, removing waves with periods greater than 7.5 seconds.

The WaveApp shows a strong positive correlation for $H_s$ in comparison with the DWR-MkIII and the DWR-G4, however, shows a negative bias (Table 5, Figure 6 and Figure 7), while $H_{max}$ has a slightly weaker correlation to both devices. Due to the filtering applied to the WaveApp data long period waves, were heavily affected, thus $T_p$ does not display a statistically significant correlation with either the DWR-MkIII or the DWR-G4. Comparison of $T_z$ showed that the DWR-MkIII and the DWR-G4 have a weak correlation with the WaveApp. Examination of goodness of fit measures showed that the WaveApp has a slightly higher correlation when compared to the DWR-G4 than with the DWR-MkIII. This highlights the benefits of having both sensors in the same device as the same wave field is being compared.

<table>
<thead>
<tr>
<th>Device</th>
<th>Method</th>
<th>$H_s$ (m)</th>
<th>$H_{max}$ (m)</th>
<th>$T_p$ (s)</th>
<th>$T_z$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR-MkIII</td>
<td>$r$</td>
<td>0.80</td>
<td>0.65</td>
<td>-0.03</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>RMSE</td>
<td>0.2</td>
<td>0.38</td>
<td>8.27</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>BI</td>
<td>-0.17</td>
<td>-0.23</td>
<td>-7.88</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Figure 4 Recalculated parameters ($H_s$, $H_{max}$, $T_p$, $T_z$) for each wave buoy compared to the DWR-MkIII with a 1:1 line.

Figure 5 Time series comparison between the SCRIPPS and DWR-MkIII.

Figure 6 WaveApp and DWR-MkIII comparison of data. Throughout the dataset, $H_s$ showed slight positive bias, while a comparison of the Scripps $T_z$ with the DWR-MkIII showed slight positive bias. Although a general uniformity between the devices was attained, as is displayed through time series comparisons (Figure 5). However, difficulties connecting to the satellite system were evident throughout the dataset, resulting in a sporadic time series which made determining a direct correlation between wave records challenging.

Table 5 Statistical tests for the of the DWR-MkIII and DWR-G4 compared to the WaveApp
parameters can be minimised. Due to the presence of saw-tooth artefacts in both moored and unmoored DWR-G4 buoys, it is unlikely that the low-frequency errors were solely caused by mooring forces. They are likely due to a combination of high-energy sea states causing GPS signal corruption, general loss of the minimum number of required GPS satellites, and tension placed upon the mooring configuration, leading to one or both of the aforementioned. In order for the DWR-G4 buoys to calculate orbital wave motion via the Doppler shift principle, a minimum of four visible satellites is required [8]. The Spotter demonstrated less frequent saw-tooth patterns in the raw displacement, possibly due to the Spotter utilising the Iridium SBD for GPS as opposed to the GPS satellite system used by Datawell.

### 4.4 Raw Heave Displacements

A comparison of a half-hour segment of raw displacements from the DWR-MkIII and DWR-G4 on 19 April demonstrates the extent to which heave measurements were influenced by GPS corruption (Figure 8). Whilst the DWR-MkIII fluctuates around 0.0 m in a relatively uniform manner, the DWR-G4 has multiple anomalies which severely impacted calculated parameters (Table 6) in both the automatic data outputs and recalculated parameters.

<table>
<thead>
<tr>
<th>Device</th>
<th>$H_s$ (m)</th>
<th>$H_{max}$ (m)</th>
<th>$T_p$ (s)</th>
<th>$T_z$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWR-G4</td>
<td>1.61</td>
<td>2.53</td>
<td>40</td>
<td>6.36</td>
</tr>
<tr>
<td>DWR-MkIII</td>
<td>1.247</td>
<td>2.22</td>
<td>14.29</td>
<td>5.128</td>
</tr>
</tbody>
</table>

![Figure 7 Recalculated parameters (Hs, Hmax, Tp, Tz) for the WaveApp compared to the DWR-MkIII with a 1:1 line.](image7)

![Figure 7 Recalculated parameters (Hs, Hmax, Tp, Tz) for the WaveApp compared to the DWR-G4 #6 with a 1:1 line.](image8)

This anomaly (known as a saw-tooth pattern that introduces erroneous low frequency energy) has been reported in a number of studies, utilising both moored and drifting DWR-G4 buoys [3] [4]. The saw-tooth like artefact occurred frequently throughout the raw displacements of the DWR-G4s and infrequently in the Spotters, and is a result of the buoy losing track due to low in GPS signal. By applying a high-pass filter to the data, the effect of these erroneous displacements on wave

Figure 8 Vertical heave displacement produced by the DWR-MkIII and DWR-G4 to demonstrate the effect of GPS loss on raw displacements. Observations are from 19 April 2018.

### 4.5 Device Longevity

Longevity of wave monitoring equipment is a significant factor to take into consideration when undertaking wave monitoring due to the harsh ocean environments that devices are subjected to during deployment. There are a number of situations that can result in ocean monitoring equipment being damaged or destroyed: lightning strikes; boat strikes; and extreme events. Datawell and TriAxys buoys are made from stainless steel (DWR-G4 and TriAxys) or cunifer alloy (DWR-MkIII) in order to resist potential damage, while Spoondrift Spotters are made from a marine grade plastic. Throughout this trial damage was sustained to the hull of the Spotters which resulted in water intrusion. Additionally, the Spotter’s size is of concern when deployed for extended periods as mooring forces and biofouling may affect the buoyancy of the device. In warmer climates biofouling is a serious concern for equipment within the marine environment. For long-term deployments of both the Spotter and DWR-G4 extensive biofouling may severely hamper a buoy’s ability to follow the orbital motion of the water, reducing the quality of wave parameters recorded and affecting the high frequency response of the buoy [19]. For GPS buoys an additional concern is that the added weight of marine growth can cause the buoy to sit lower in the water, becoming more susceptible to wave over topping thus causing GPS interference. Additionally the DWR-G4 is limited by a 4–6 week battery life. Due to the submerged nature of the pressure transducers biofouling was apparent, however, no negative effects on wave parameters records were apparent. Both the DWR-MkIII and TriAxys buoys were subject to barnacle growth, but they were not notably affected due to the size and subsequent buoyancy of the devices. However, consideration of biofouling for long duration deployments is recommended.
5. Summary
It was determined that wave parameters collected by Spoondrift Spotters, Datawells DWR-G4s, Metocean’s TriAxys, RBR and the Aanderaa have a statistically significant correlation to the DWR-MkIII both in automatic outputs and recalculated parameters. The TriAxys buoy consistently performed well in comparison to the DWR-MkIII, as did the Spotters. However, the Spotters do not provide Hmax in their automatic outputs. The DWR-G4 experienced irregular GPS corruption due to signal loss, which impacted some of the automatic wave parameters, particularly Hmax, and Tp. However, the correlation for recalculated peak period improved significantly with filtering and erroneous record removal. The Aanderaa had average performance in comparison to the DWR-MkIII, showing a negative bias for Hmax and Tz. The RBR displayed particularly weak correlations for Tp and Tz in addition to a negative bias for Hs and Hmax.

The weak agreement apparent in the pressure transducers recording of wave period could possibly be attributed to the variances in record length (8.5 minutes compared to 26.6 minutes) preventing the measurement of the peak period. Due to the absence of a live data feed for both the Aanderaa and RBR, deployment applications are limited. It is important to note, however, that while each device has a correlation, these relationships are of varying strengths dependant on the wave parameter and device. The RBR in particular, demonstrated a consistently weaker correlation across Hs, Hmax, and Tz.

Device longevity was highlighted as an issue for the smaller buoy designs, due to the failure of the Spoondrift Spotters buoys caused by water incursion and the need to replace batteries on the DWR-G4. With a more durable design the Spoondrift device could provide a promising alternative for longer-term ocean monitoring. There is still uncertainty as to the reliability and robustness of the tested instruments over an extended period and during extreme conditions. However, the DWR-G4 has previously been deployed into cyclonic conditions with promising results, produced by filtering the raw displacements and recalculating wave parameters.

5.1 Limitations
While the authors endeavoured to undertake a comprehensive comparison of wave monitoring equipment there were a number of limitations, primarily, due to spatial differences, measurements of the exact same wave were not possible. Future trials would benefit from an on-board inter-sensor deployment where the sensors of each device are deployed within one hull. Additionally this will minimise variations caused by alternate mooring configurations and hull designs, allowing a direct comparison between each sensors ability to measure waves.

6. Conclusion
The results presented from this three-month comparison trial have revealed a number of strengths and weaknesses of several wave monitoring devices. Overall, a strong correlation was discovered for parameters Hs, Hmax, and Tz in comparison to the DWR-MkIII, while Tp returned the weakest correlation across all devices compared to the DWR-MkIII. There was a notable difference between the performance of the wave buoys and the pressure transducers, particularly when measuring wave period.

In order to conduct wave monitoring, multiple factors need to be considered prior to deployment to determine the most suitable device. For example, location, depth, deployment duration, wave energy, and project objective are all crucial in deciding which wave monitoring device is the most suitable for a particular application. The results of this study may provide a good starting point for deciding which type of device might be the most appropriate for future wave measuring applications. For further information regarding this study, including in-depth analysis techniques, recommendations and mooring comparisons, the author recommends reading the in-depth report [1].

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8. References


