Department of Science, Information Technology and Innovation

Mk4 Datawell Wave Buoy Analysis and comparison

A comparison between the Mk4 and Mk3 Datawell Directional Waverider Buoys

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Queensland Government

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Introduction

The Coastal Impacts Unit of the Department of Science, Information Technology and Innovation has recently started the deployment of a new version of a Datawell DWR (Directional Waverider Buoy). On paper these buoys are an improvement on the existing design and include new features not previously seen, such as current measurement. For all the potential benefits of the new buoy there are some differences in the design and analysis techniques between it and existing buoys which could impact long-term wave measurements that are stored by the Coastal Impacts Unit. The following report aims to investigate some of the differences between the Mk4 and Mk3 DWR so that changes in the long-term records associated with the change in buoy can be identified and documented. It should be noted that for the purposes of this comparison that both the Mk3 and the DWR-GPS are referred to as Mk3; this is because they use the same spectral schema, similar analysis techniques and data parameters. The data used in this report stems from a comparison between an Mk4 and Mk3 DWR for seven months followed by Mk4 DWR and DWR-GPS for three months.

This report aims to further develop our understanding of the differences between the Mk3 and Mk4 building on a comparative report created by Datawell (Datawell 2012), with specific emphasis the current fleet used in Queensland.

Background

The DWR Mk3 accelerometer buoy

The Mk3 buoy measures wave height using a single accelerometer mounted on a gravity-stabilised platform. Wave displacement is calculated from filtering and then double integration of the acceleration. Direction is calculated from correlating the horizontal motion with the vertical motion. The horizontal motion is determined from two perpendicular accelerometers in conjunction with coils for sensing pitch and roll, and a fluxgate compass to relate the horizontal displacements to magnetic north. Further detail can be found in the Datawell manual (Datawell, 2017a).

The buoy caters for the physical limitations of the buoy by using band pass filtering. Initially, the analog outputs are passed through an analog low-pass filter with a cut off frequency of 1.5 Hz, as the buoy cannot respond to frequencies comparable to the buoy’s dimensions. The signals are then digitised at a sampling rate of 3.84 Hz, and transformed into north, west and vertical accelerations. Finally, a digital high-pass filter of 30 s is applied (as the accelerations at lower frequencies become comparable to the sensor noise) and the data is converted to a sampling rate of 1.28 Hz, and the velocities are double integrated to give displacements. Datawell states a resolution of 10 mm, with a range of −20 m to +20 metres.

Along with the displacements in the three primary directions, the on-board processing provides wave parameters based on directional spectral analysis. The buoy applies a non-overlapping Welch method in that a Fast Four Transform (FFT) is undertaken every 200 s (or 256 samples) utilising a Tukey window. The energy spectra is then smoothed using a 3 point weighted moving average (refer Datawell, 2017a). Finally, the spectra from eight consecutive 256 point segments are averaged (a total of 1600 s) to provide estimates of energy, mean direction, spread, skewness and kurtosis. Each cycle commencing at half hourly cycles. The manual is silent as to whether any error checking is undertaken for each segment.

To conserve data storage and transmission, the spectrum file keeps 64 frequency bins:

f = 0.025 to 0.1 Hz, Δf = 0.005 Hz (i.e. all computed frequency bins)

f=0.1 to 0.58 Hz, Δf = 0.01 Hz (i.e. every second computed frequency bin).

Once the displacement and spectral data are transmitted to the onshore receiving station, further analysis is undertaken by Datawell software to provide time domain statistics.

GPS Buoy (DWR-G)

The GPS buoy employs the same post processing as the Mk3 accelerometer buoy in relation to the on-board spectral estimates and time domain statistics derived from the shore receiving software. The differences relate to the measurement scheme for the accelerations.

The DWR-G hardware determines the velocity of the buoy using the Doppler shift in the GPS signal. Integrating the velocity provides the 3-dimensional displacement of the buoy, the directions being relative to true north. The velocities, which are sampled at 2 Hz, are passed through a digital integrating high-pass filter with a cut off of 0.01 Hz. The data is then converted to 1.28 Hz through the use of a decimation filter with a 43 s delay. As with the Mk3, Datawell states a resolution of 10 mm, with a range of −20 m to +20 metres.

Unlike the accelerometer buoy, the GPS buoy is therefore affected by factors that may interrupt the signal. These include GPS loss from large or breaking waves washing over the antenna, position changes over 100 m in less than 100 s (more related to drifting buoys), or any other factors that may interrupt the signal strength such as buoy tilt, atmospheric conditions, and the number of discoverable satellites. The impact of this signal loss on wave spectra has been documented in Björkqvist et al., (2016) and Boswood et al., (2017).

The Mk4 accelerometer buoy

The Mk4 accelerometer buoy employs the same measuring techniques and filtering approach as the Mk3 accelerometer buoy (refer above). The differences relate to sampling, storage and post processing. The Mk4 samples the filtered analog signal at 5.12 Hz (refer Datawell 2017b). Following the digital filtering (refer Mk3 above) the vertical, north and west displacements are recorded at 2.56 Hz, giving twice as many samples as the Mk3 for the same period of measurement. The measuring range is still −20 m to +20 metres. However, the resolution varies from 1 mm for small values to 40 mm at the maximum displacement of 20 metres, due to a change in the encoding approach to an inverse hyperbolic sine. The Mk4 will also record a NaN when the buoy measures accelerations greater than 1 g (i.e. breaking waves hitting the buoy).

An increase in sampling frequency has a corresponding increase in frequency bandwidth. The Mk4 produces directional spectra based on a 50 per cent overlapping Welch method with a Hann window. Each segment is still 200 s, giving 512 samples for each segment. The moving average applied to each segment’s spectra in the Mk3 is not used in the Mk4. Instead, the Mk4 averages 17 spectral estimates every half hour. The Mk4 will also reject segments should there be an error in a sample. A separate message provides details of any segments that were rejected (Datawell 2017c).

With the increase in bandwidth, the Mk4 keeps 100 frequency bins:

f = 0.025 to 0.25 Hz, Δf = 0.005 Hz (i.e. all computed frequency bins)

f= 0.26 to 0.58 Hz, Δf = 0.01 Hz (i.e. every second computed frequency bin)

f= 0.60 to 1.00 Hz, Δf = 0.02 Hz (i.e. every fourth computed frequency bin)

The Mk4 also measures surface currents (speed and direction) every 10 minutes at approximately 1m depth below the buoy by an acoustic current meter comprising three acoustic transducers in the hull (Datawell, 2017b).

Additional features of the Mk4 are explained in the proceeding section.

Major Differences

The resolution of the raw displacement (heave) data has been improved by increasing the on-board capacity of the buoy so it is able to record heave measurements from the accelerometer to 12bit floating point notation. This is significant compared with the Mk3 and gives some credence to achieving the millimetre precision for values as stored by Datawell. However, as pointed out in Datawell's technical report, this cannot be achieved in storm conditions. It is estimated that if a record is valid and achieves 20 m wave height then the maximum precision that could be achieved is 4 cm (Datawell 2012). Note, the millimetre precision does not denote accuracy which is still < 0.5 per cent of the measured value.

A key operational difference between the Mk3 and the Mk4 is the use of online up-crossing wave statistics which are calculated on the fly by the Mk4, unlike the Mk3 where data was all post processed. Although in theory this is an improvement on the Mk3 there are some practical issues: first is the time it takes the onshore software to add this data into the csv file message; second is that Hs is no longer calculated via the commonly used zero up-crossing method but is estimated using Hrms√2, as highlighted in the Datawell manual and technical note (Datawell 2012, Datawell 2017).

Data types and timestamping have long been an issue with Datawell DWRs and the Mk4 has brought in a wave of significant improvements in this space. Previously messages often only came with a timestamp on the file and often there was a difference in timing between the different messages. Now with the Mk4 each and every record now includes a timestamp and every message type is generated as a CSV.

One of the most notable changes with the Mk4 is the addition of current data, which is recorded by three acoustics sensors in the hull. Together they produce surface current speed and direction information, a particularly useful addition for those that historically installed additional instrumentation to get current information. This addition of this shines a light on other potential instrumentation to Datawell buoys to make them a true multiplatform ocean monitoring platform.

Previous Comparisons

Datawell (unknown) undertook a comparison of Mk3 and Mk4 accelerometer buoys based on a deployment offshore from Ymuiden, The Netherlands from 29 November to 22 December 2011. They compared both frequency and time domain derived parameters. Four spectral parameters (significant wave height (Hm0), mean period (T1), zero-upcross period (Tz or T02) and the crest period (Tc).were compared. The comparison included a reanalysis of the Mk4 spectra based on the Mk3 spectra scheme and frequency bins. The results showed good agreement between reanalysed Mk4 and Mk3 parameters. The original Mk4 parameters based on the extended bandwidth (i.e. from 0.60 to 1.00 Hz) showed good agreement with Hm0 but slightly lower values with parameters derived from higher order moments, the greatest difference being for Tc. The reasoning for this can be seen when we look at the equations for Hm0 and Tc.

$$Hm0 = 4\sqrt{m_0} \qquad \text{Eqn (1)}$$

$$Tc = \sqrt{\frac{m_2}{m_4}} \qquad \text{Eqn (2)}$$

Where m_n is the nth spectral moment defined by:

$$m_n = \int_{f1}^{f2} f^n S(f)df \qquad \text{Eqn (3)}$$

Depending on the energy contained within the Mk4 extended higher frequency range (0.60 to 1.0 Hz), it can be seen that the power term will result in reductions in Tc compared to the Mk3 with a cut-off at 0.58 Hertz.

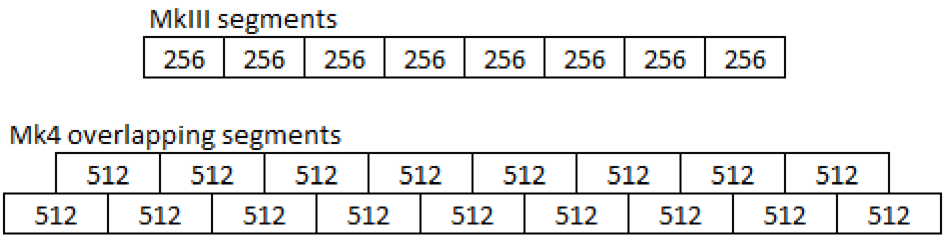
The time domain comparison included zero up-crossing parameters processed on-board the Mk4 (highest wave Hmax, the period of the highest wave T(Hmax), the average wave height Havg, the average wave period Tavg, and the significant wave height Hs (based on the root-mean-square wave height Hrms)) against similar parameters derived from Datawell's post-analysis software. Datawell concluded good agreement for the wave height parameters, except during a storm with Hsig > 6 m, which was contributed to data quality control. In relation to the wave period parameters, Datawell concluded a generally good agreement for T(Hmax). The average wave period showed concurrent trends with the Mk4 values being slightly lower. This was contributed to the higher sampling rate of the Mk4 picking up shorter period waves as well as the higher resolution of the smaller values near mean sea level (1 mm for Mk4 versus 10 mm for Mk3).

Finally, Datawell looked into individual spectra (both directional and non-directional), showing one example for a 30 min period. Despite the differences in spectral schemes, recording times, and frequency bins, there was generally good agreement in the frequency bins that corresponded, the DWR4 providing higher resolution detail in both the mid and high frequency ranges. The main differences occurring from parameters that involve higher order moments such as directional skewness and kurtosis.

Spectral Schema Comparison

Spectra Schema

The spectra of the Mk3 and Mk4 are calculated using two different methods: the Mk3 uses a non-overlapping approach with a Tukey window; whereas, the Mk4 uses overlapping segments with a Hann window.



The spectral schema has also been changed in the Mk4 with the change from 64 to 100 bins; there is a change in the bin widths with a new bin width used. The frequency range of the bins has also changed with the Mk4 extending out to 1 Hz over the Mk3's 0.58 Hz. Although in theory the same total amount of energy measured should be similar, in practice energy is likely to be spread between bins with the Mk4 schema, will likely be folded into one bin in the Mk3 schema.

$$f_k = \begin{cases} 0.025 + 0.005 \cdot k & \text{for } k \text{ in } [0..46) & \text{range}[0.025..0.25] \\ -0.20 + 0.010 \cdot k & \text{for } k \text{ in } [46..79) & \text{range}[0.26..0.58] \\ -0.98 + 0.020 \cdot k & \text{for } k \text{ in } [79..100) & \text{range}[0.60..1.00] \end{cases} \cdot \text{Hz}$$

Mk4 spectral schema (Datawell 2017)

$$f_k = \begin{cases} 0.025 + 0.005 \cdot k & \text{for } k \text{ in } [0..15] & \text{range}[0.025..0.1] \\ 0.1 + 0.010 \cdot (k - 15) & \text{for } k \text{ in } [16..64) & \text{range}(0.1..0.58] \end{cases} \cdot \text{Hz}$$

Mk3 spectral schema (Datawell 2017)

As a third comparison, the spectra was also recalculated for both DWRs using non-overlapping segments (Violente-Carvalha et al., 2004), with a Hann window; the main aim was to understand the difference in windowing methods. However little difference was found other than perhaps a slightly reduced spectral leakage compared with the Mk3's approach; this has therefore been excluded for the purposes of this comparison and may be the subject of further work.

Spectra

The spectra in Figures 1 and 2 have been recalculated from the displacements as there is a timing mismatch between the Mk3 and Mk4 spectral messages, making them difficult to directly compare. The methods of calculation used are outlined in the section above and show good agreement with spectra calculated by the Mk4.

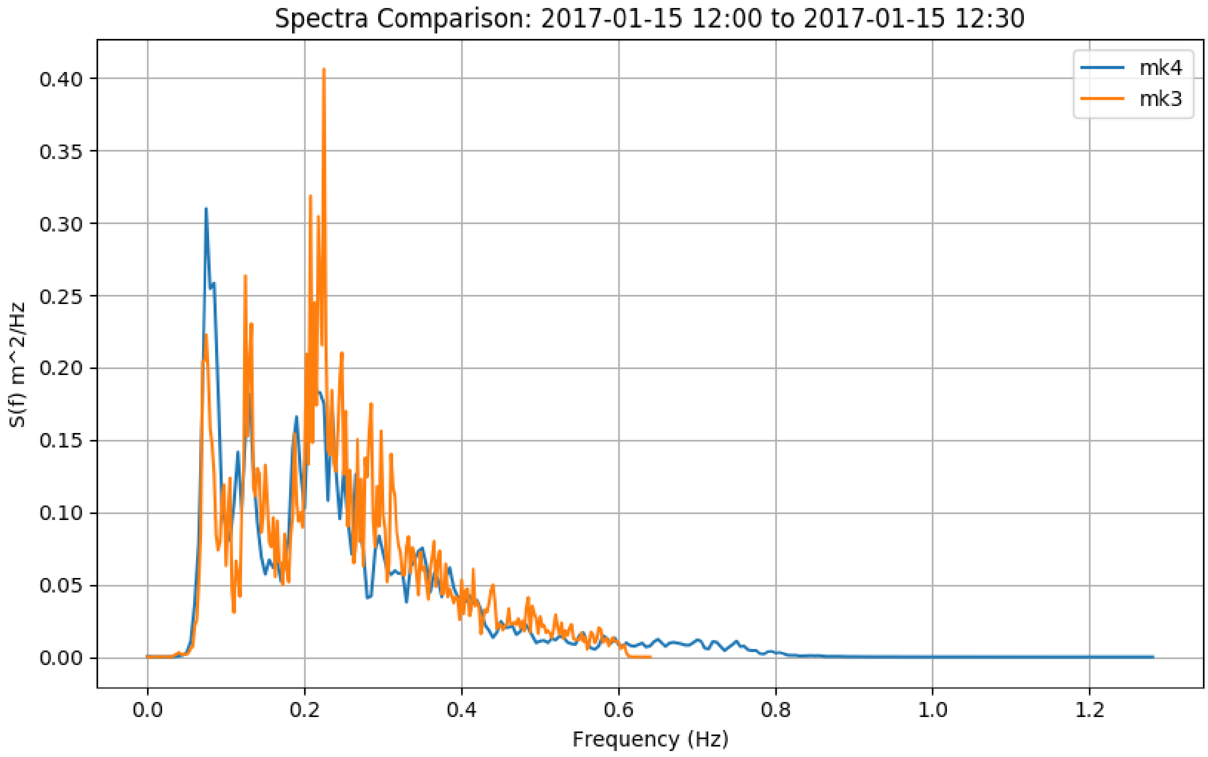


Figure 1: A comparison of recalculated spectra from Brisbane, Mk3 and Mk4 site.

Figure 1 above shows that the Mk4 and the Mk3 DWRs have picked up a completely different energy peak, which means for this record the peak period is different as in the table below.

Table 1: A summary of wave statistics from Mk3 and Mk4 DWR 2017-01-15 12:30

Parameter	Mk3	Mk4
Tp (sec)	4.55	13.33
Tz (sec)	3.77	3.27
Hmax (metres)	1.26	1.38
Hm0 (metres)	0.79	0.84

This potential for significant differences of Tp during bimodal conditions should be noted when comparing long-term trends, however, it is not clear from the limited data whether a particular buoy trends towards either longer of shorter period peaks. It is also unclear whether there is a difference between the DWR types as to when this occurs, nor is it possible to determine which DWR is ‘correct’, due to the comparison method we are using and as no third party data available.

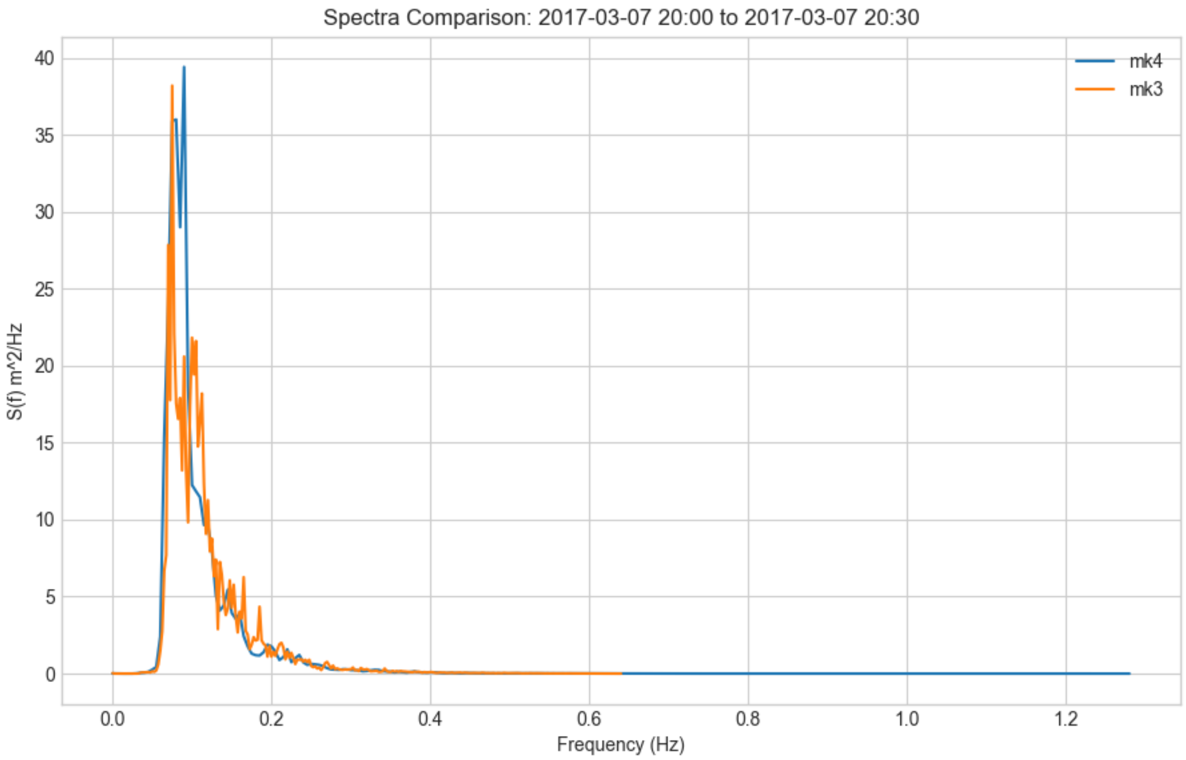


Figure 2: A comparison between the Brisbane Mk3 and Mk4 recalculated spectra under a more developed sea state.

Unlike the previous spectra the above shows more similarities between the Mk3 and the Mk4. The spectra above seems more typical of the differences in spectra between the two buoys (bearing in mind the two buoys being compared are moored near one another) – the total energy is almost always very similar – and this suggests that the Mk4 might be folding the energy into slightly different frequency bins. The spectra are similar in more developed sea states and this is likely due to energy being overwhelmingly from one source, in this case a storm.

Table 2: A summary of wave statistics from Mk3 and Mk4 DWR 2017-03-07 20:30, during a storm event.

Parameter	Mk3	Mk4
Tp (sec)	11.76	13.33
Tz (sec)	7.84	8.09
Hmax (metres)	7.28	7.93
Hm0 (metres)	4.69	5.11

Data Comparison

Hm0

Hm0 is calculated using the zeroth moment from the power spectrum density (4 √m0). This is the same for both DWRs, however the different sampling frequencies suggests that Hm0 should be different. Datawell suggests that the Mk4 should show a reduction against the Mk3 (Datawell 2012), although this is not quantified.

The graph below shows almost six months of Hm0 data for a Mk3 accelerometer buoy and a Mk4, and as you can see generally they correlate very well: statistically speaking they have a R^2 correlation of 0.98.

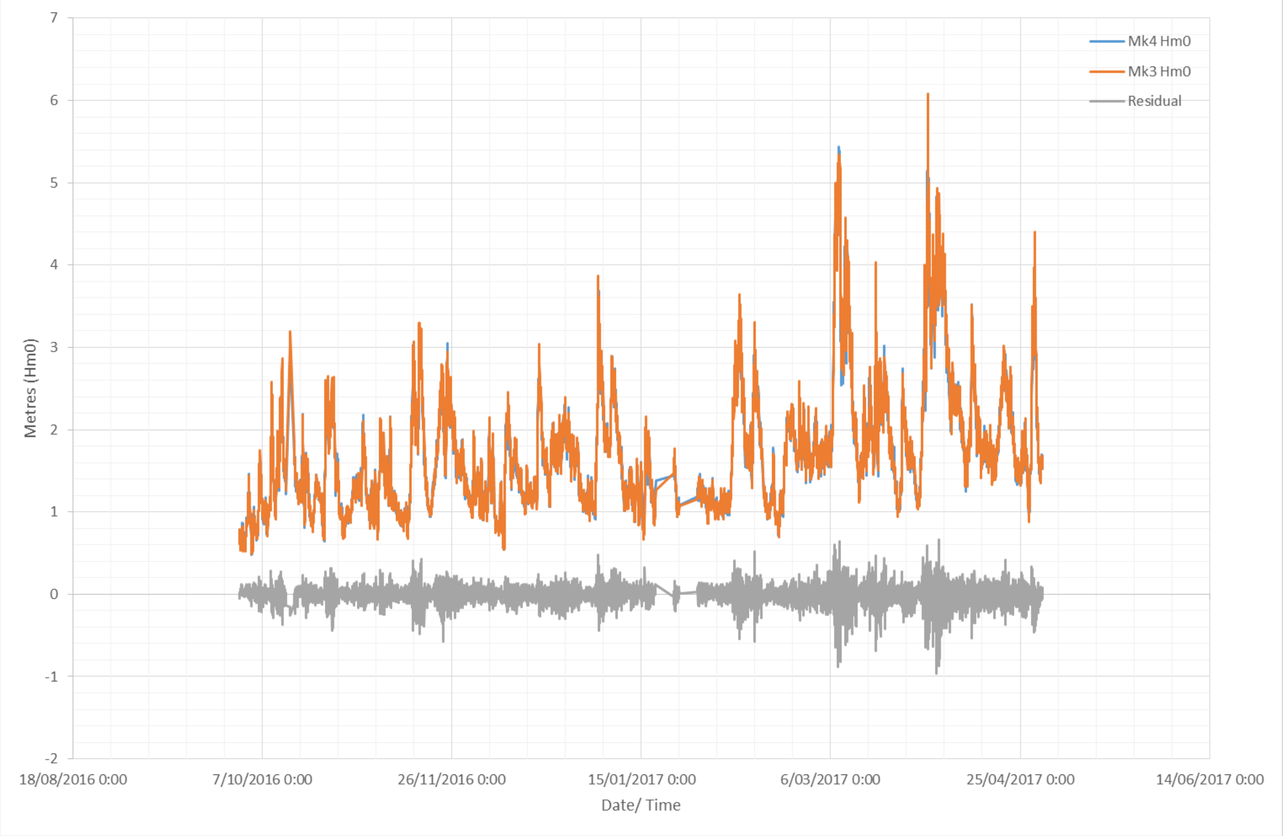


Figure 3: A comparison of four months of data between Mk4 and Mk3 on a dual deployment.

The residuals suggest that the two buoys more closely match Hm0 under moderate conditions, and are more disparate under higher energy conditions. However, it is important to note that the two generate their spectra differently (from which Hm0 is derived) – they have different frequency bins and different sampling frequencies as well as being at slightly different locations. As Datawell point out in their report (Datawell 2012) the Mk4 should be more accurate in these conditions, but this is not possible to prove either way from the data available.

A five-day comparison of the data shows more detail and, broadly, that Datawell's observations are corroborated – the Mk4 Hm0 seems to trend slightly lower than that of the Mk3.

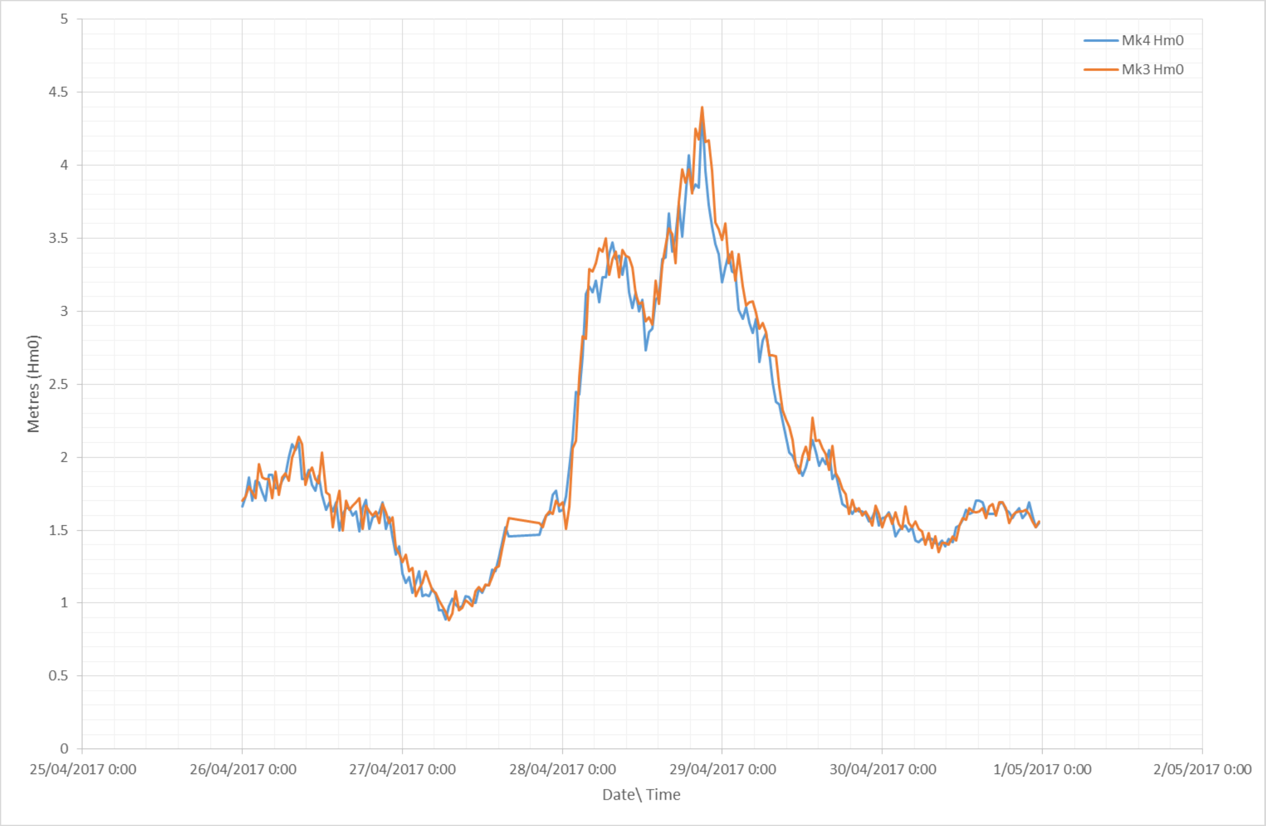


Figure 4 A comparison of five days of Hm0 data between and Mk3 and Mk4

A comparison of Hm0 between the Mk3 and Mk4 reveals that there is very little difference between the two buoys. Almost six months of data was analysed and although there are some differences, overall they match very well as shown in the linear regression below ($R^2 = 0.98$). As highlighted previously the difference between the two DWRs is greater in higher energy conditions

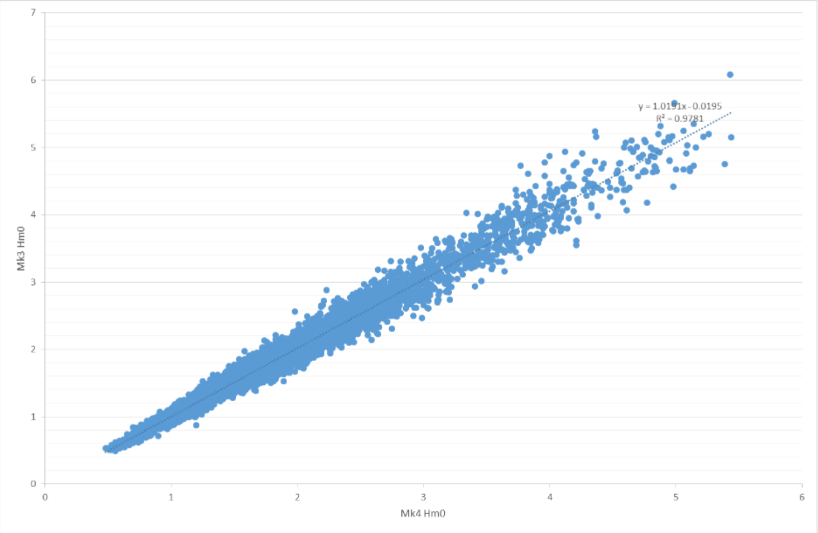


Figure 5 A comparison of five days of Hm0 data between and Mk3 and Mk4, with a linear trend line (1:1)

T02/Mk4 Tz

Datawell has changed the way the parameter Tz is calculated in the Mk4 to use T02 (instead of the time domain derived Tz in the Mk3), however both buoys produce this statistic which is derived from the frequency domain. Although both are calculated the same way, they are derived from spectra calculated in a different way.

The six months of data below suggest overwhelmingly that the Mk3 shows a higher period than that of the Mk4. As pointed out in Datawell's technical note (Datawell 2012), this is likely associated with the changes with the Mk4, especially the increased frequency range at higher frequencies which in turn has an impact on spectral moments outside of the zeroth moment.

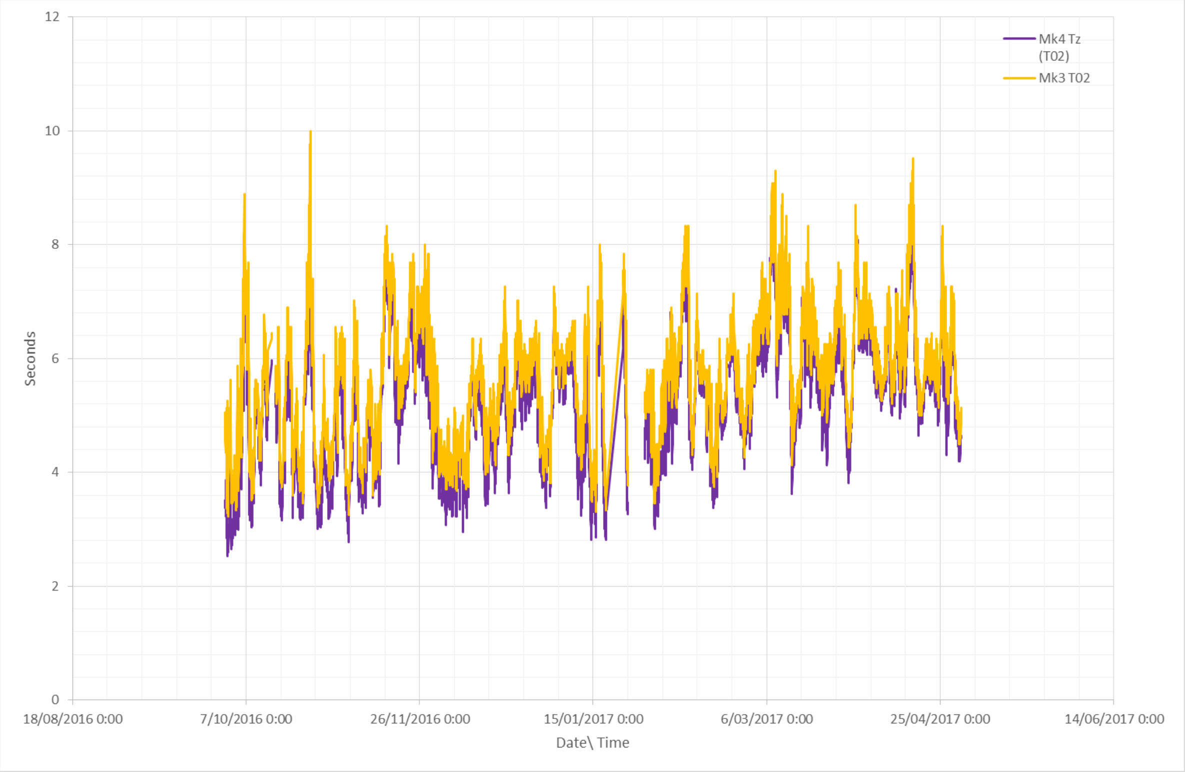


Figure 6 A comparison of six months of T02.

A statistical comparison (R2 = 0.92) suggests they generally agree; however, the Mk3 shows generally increased periods for the same records. The change is likely to be caused by the spectral schema in the Mk4, as M02 is used to calculate the T02 will change significantly as the number of bins and the bin widths have changed. A further contributing factor is likely to be the spectral smoothing that occurs when using an overlapping segment method when calculating spectra.

Table 3: A comparison of standard deviations of T02

Buoy	Standard Deviation
Mk3	1.097
Mk4	1.149

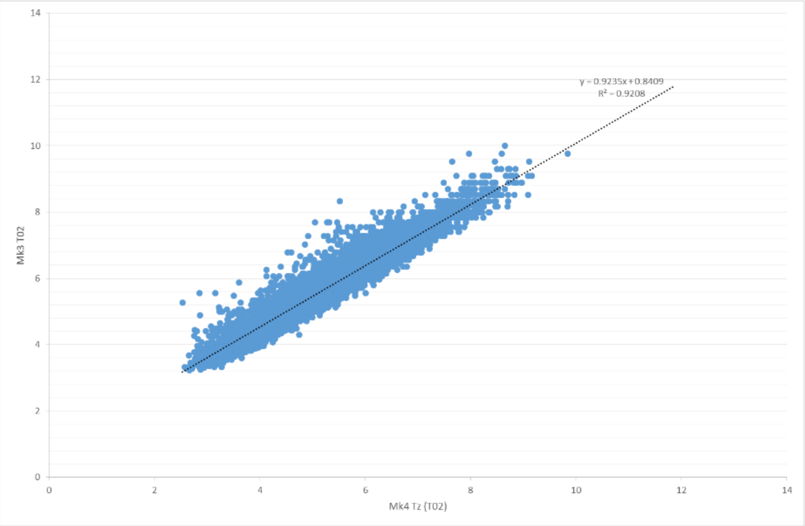


Figure 7: A six month comparison of the relationship between T02 and Tz (T02), with a linear trend line (1:1)

Tp

Tp is the period of the peak wave energy and is calculated from the power density spectrum. It is important to note that although both the Mk3 and the Mk4 calculate it in a similar way, the sampling frequencies and spectral bins are different and, as a result one, might expect to see some differences.

As seen in the figure below (as a six month comparison of Tp) generally they seem to trend together well; if anything there seems to be larger peak period being produced by the Mk3.

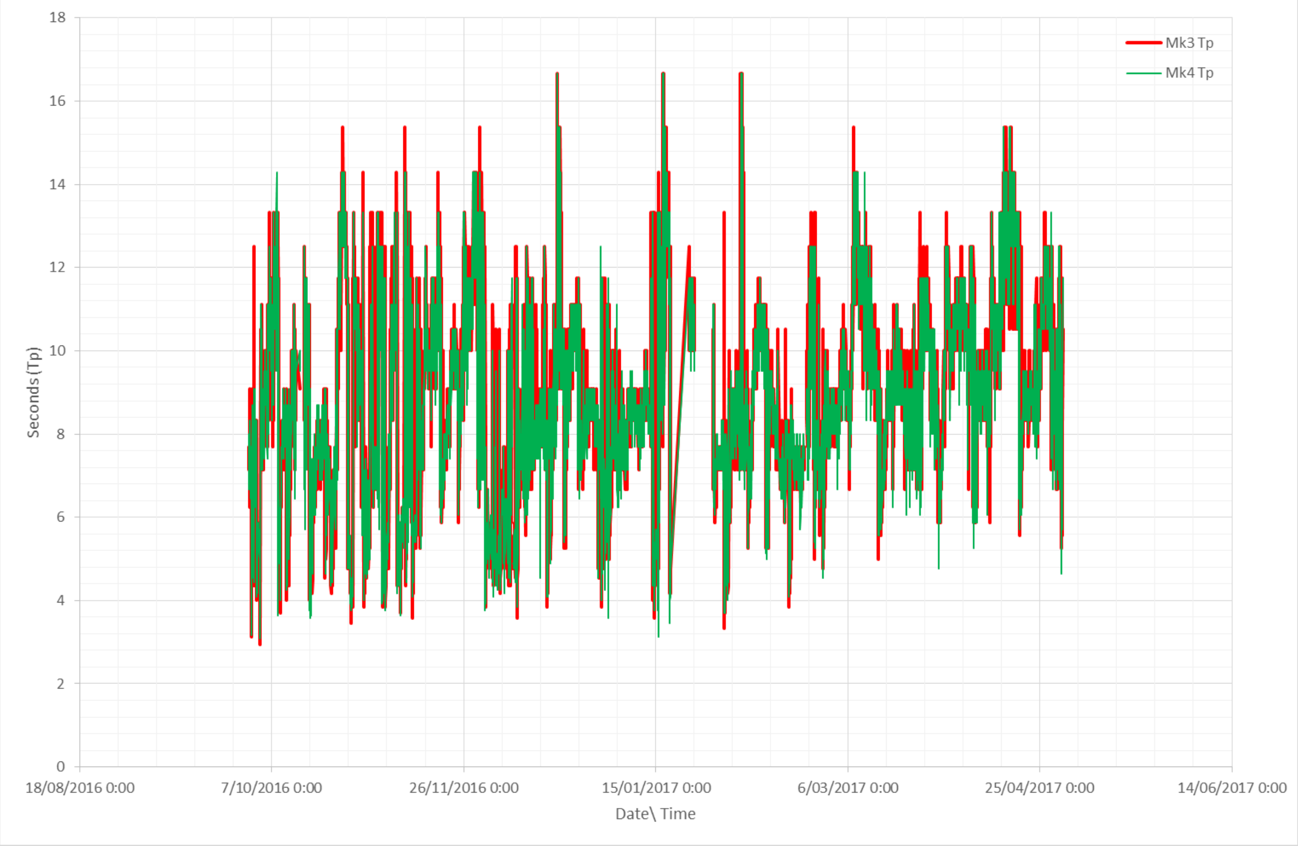


Figure 8 A comparison between Mk3 and Mk4 Tp over six months

Although there might seem to be a trend between the Tps, there are some significant differences in the individual records and it is almost impossible to draw a direct comparison between the two other than in storm conditions where the energy from a particular source (e.g. locally sourced storm associated wind waves) dominate the spectra. This could be caused by switching between different peak periods during bi-modal conditions. Another possible explanation is difference in frequency bins between the two buoys meaning that they assign the energy slightly differently to different frequencies.

This is reflected statistically where the average Tp over six months for the Mk3 is nine seconds and for the Mk4 8.8 seconds, however the R^2 is 0.76.

A five-day comparison of Tp below highlights the differences between the two DWRs. During the first two days of the record the dominant frequency/period is comparable. However in the latter half of the period this becomes less clear and the differences between the DWRs become more pronounced.

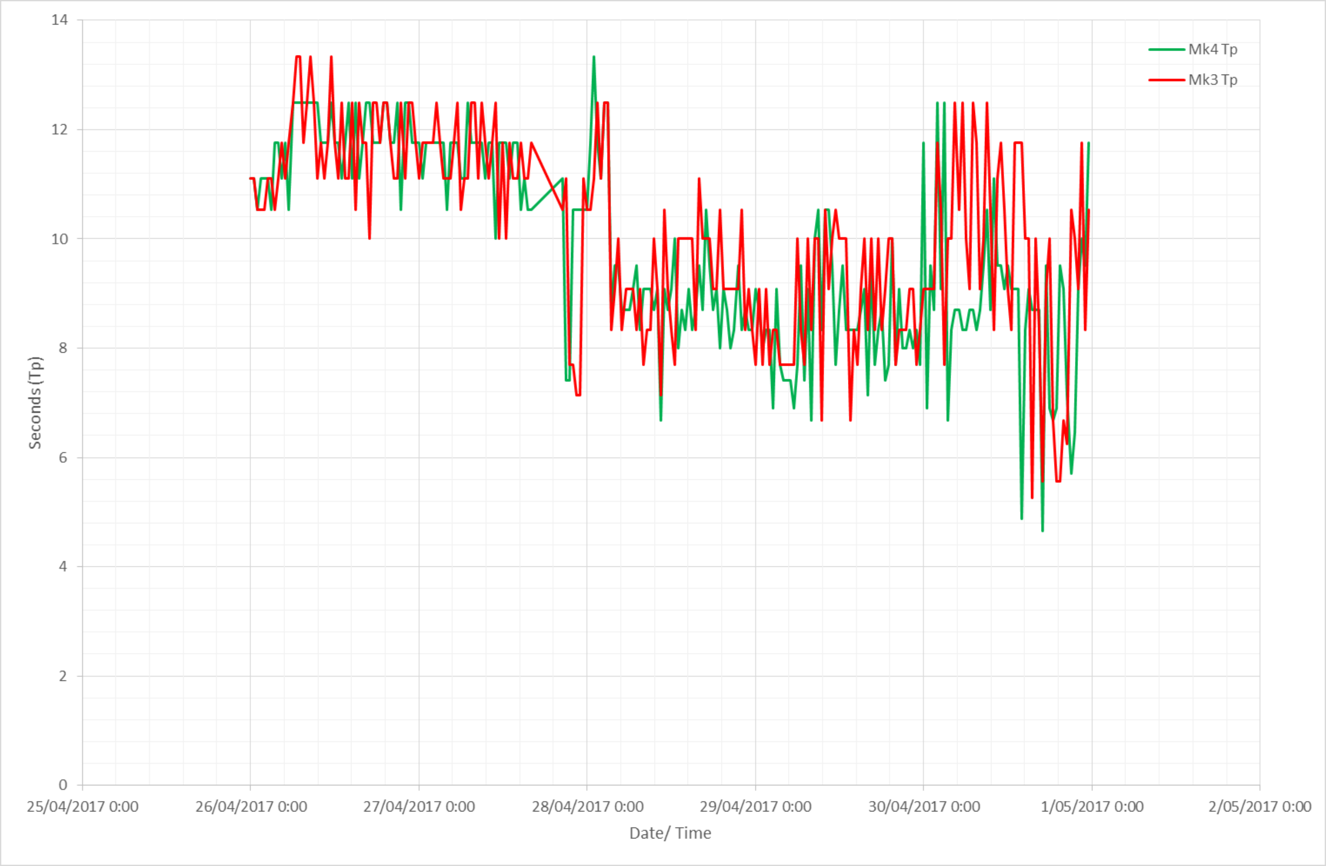


Figure 9 A five-day comparison between Mk3 and Mk4 Tp

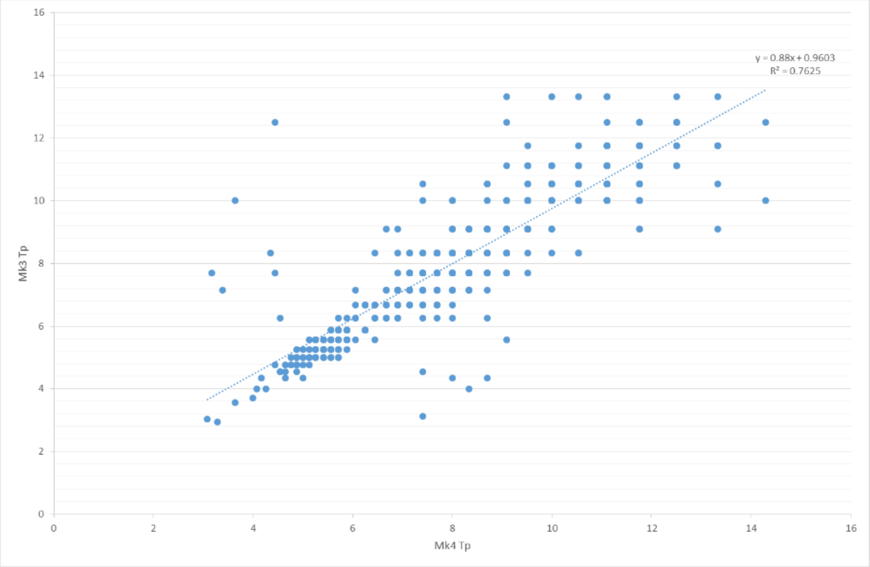


Figure 10: A six month comparison of the relationship between Tp, with a linear trend line (1:1)

In summary, when comparing Mk3 and Mk4 Tp, it is important to note the sea state at the time. For longer-term records the sea state is likely to have a limited impact, but for comparisons during more complex sea states (especially bimodal) care should be taken.

Direction

The representative direction by both DWRs is the SMAX Direction. This is the direction of the peak energy and both also take preference of the lowest frequency if two spectral bins are the same. However this is where the similarities end. The Mk4 has more spectral bins and as highlighted previously has a differing sampling rate. As with Tp, the SMAX will be different inherently between the Mk3 and Mk4.

The graph below suggests that despite the buoys' differences they generally trend very well; however, this is not the same during bimodal conditions. The Mk4 direction shifted dramatically on 20 June 2017 as the energy from a different spectral bin was slightly more. This is more typical of behaviour in calmer conditions, where wave energy between different spectral bins are very close.

Figure 11 A 20-day comparison of Tweed Wave Buoy data. (Mk4 direction is in degrees magnetic and Mk3 is in degrees true)

Great care will need to be taken when comparing Mk3 and Mk4 directional data as there can quite often be legitimate differences between the two.

Conclusion

Although there are some key differences between the Mk3 and the Mk4, generally the Mk4 shows some improvements and future updates suggest these will be further enhanced throughout the lifetime of the Mk4.

Users switching between the Mk3 and Mk4 are likely to notice only a small difference in the wave statistics day to day and the Mk4 certainly represents an improvement over its predecessor in terms of data structures. The key improvements noted include: more accuracy; increased sampling frequency; some basic data validation; and file formats. Ultimately outputs from the two buoys will be different – this seems predominantly due to different calculation methods, sampling frequencies and other changes that Datawell have made for the Mk4.

Importantly, for long-term data analysis, the difference in data output from the different DWR types should be considered, as analysis has suggested this is especially important when looking at peak wave period (Tp) and peak energy direction (SMAX Direction).

The Mk3 and GPS buoys showed similar differences to the Mk4 throughout the comparison, although further work could conceivably show differences. A further longer term study would likely need to be carried out.

Recommendations

Users of the data for long-term monitoring applications should be mindful of the changes between the different DWRs, especially if it involves parameters that might be derived from the spectral domain. This is especially important as parameters in different buoy types might be labelled the same but calculated using a different method. A small technical note outlining those differences could be sent with Mk4 data as metadata to help clarify this.

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Glossary of Terms

Parameter	Description
THsig	The average period of the highest one-third of zero up-crossing wave heights
Hrms	Root mean square wave height from the time domain
Hmax	The maximum zero up-crossing wave height (in metres)
Tz	The average of the zero up-crossing wave periods (in seconds)
Hm0	Estimate of the significant wave height from frequency domain $4\sqrt{m_0}$
T02	Average period from spectral moments zero and two, defined by $\sqrt{m_0/m_2}$
Tp	Wave period at the peak spectral energy (in seconds). This is an indication of the wave period of those waves that are producing the most energy in a wave record. Depending on the value of Tp, waves could either be caused by local wind fields (sea) or have come from distant storms and have moved away from their source of generation (swell).
SMAX	The peak energy from the power density spectrum.
SMAX Dir	The direction of the peak energy from the power density spectrum.