TRIAXYS g3 Directional Wave Sensor

Latest Developments for Next Generation Wave Sensor Technology

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Abstract—**The TRIAXYS Directional Wave Sensor has been a leading technology for directional wave measurements since its inception in the late 1990's. Many technical product improvements have been made over the years related to the onboard micro-processor and the inertial sensor to capture raw motion data, to reduce the physical size and to lower power draw. This paper will provide a brief history of the technology evolution the TRIAXYS wave sensor has undergone, from its original release in 1998 through each of the incremental improvements to the most recent technical advances in the next generation of the sensor the TRIAXYS g3. The discussion on the TRIAXYS g3 will include: 1. User configurable frequency partitioning in real-time: wave analysis performed on total spectrum plus two sub-ranges within total spectrum 2. Refactored messages: reduced bandwidth for real time data using Protocol Buffers, user selectable wave statistic ranges and directional spectra 3. Continuous wave analysis and processing output: rolling sample period with data sent every minute 4. Significant reductions in physical size and power consumption. Results from validation studies conducted off the West Coast of Vancouver Island and the German North Sea are presented comparing the wave measurement performance of the TRIAXYS Next Wave II and TRIAXYS g3 sensors co-located in a single TRIAXYS directional wave buoy. A comparison of the wave statistics and energy spectra, between the two sensors, will be discussed. This report outlines how wave sensor technology has advanced over the last 17 years, how the TRIAXYS g3 and TRIAXYS Next Wave II sensors perform comparatively, and how users can benefit from the recent technical improvements to receive comprehensive information on ocean waves for various studies and requirements.**

I. INTRODUCTION

Moored buoys equipped with meteorological and oceanographic (metocean) sensors have been providing data for almost forty years. The data acquired and provided by moored buoys has long been considered the best quality of data, in comparison to data gathered by ships of opportunity or other means. Advantages including fixed location of time series data, placement of sensors, sampling and averaging of measured values, access to the data in real time, and the ability to remotely communicate with the buoy to view diagnostics and configure sensor operations, all make the use of moored buoys a preferred method of gathering metocean data.

The measurement and analysis of wave data is required to support many coastal and oceanic programs. Typical applications include: operational support (Oil&Gas, Offshore Construction, Dredging, Ocean Renewable development, etc.), ocean forecasting and Construction Design Studies and research and development initiatives related to ocean stewardship. Climate studies, and the like, require a minimum of 1 year of continuous, reliable wave data. When wave data is required for operational services, a data acquisition system must be robust with little need for servicing and maintenance.

This paper discusses AXYS Technologies TRIAXYS™ g3 wave sensor and how this revolutionary sensor compares to the previous model, the TRIAXYS NWII, in wave sensing capabilities and performance. The advancements in the new TRIAXYS g3 technology continue to entrench the TRIAXYS line of wave sensors as the industry leader for the acquisition of wave data.

II. SHORT HISTORY OF THE TRIAXYS SENSOR DEVELOPMENT

The TRIAXYS sensor initial development was the commercialization of a system designed and tuned by the National Research Council of Canada - NRC Canadian Hydraulics Centre (NRC-CHC) for the measurement of waves in their scaled multi-directional wave basins. The motion analysis software is based on the MOTAN inertial motion measurement system developed by the CHC to measure the motions. TRIAXYS uses a unique algorithm based on Fast Fourier Transfer (FFT) techniques to solve the non-linear equations that relate the buoy motions to the accelerations and angular rates measured by the strap down sensors. The roll and pitch induced accelerations due to earth gravity are removed by the algorithm to produce accurate time series measurements of heave, roll, pitch, surge, sway and yaw which is used for input into the wave analysis software. The wave analysis software used in the TRIAXYS sensor is based on GEDAP software, originally developed at NRC-CHC [2], but is now widely used around the world for random wave generation and analysis in basins including artificially generated multidirectional waves. The wave analysis algorithms first perform zero-crossing analysis of the wave elevation record in the time domain, then computes standard wave parameters including the average, significant and maximum wave heights, average wave period, etc. Next the non-directional wave spectrum is computed using FFT procedures along with various spectral parameters including Hm0, Tp, and Tp5, where Tp5 is the peak wave period computed by the Read Method [1]. Further directional wave analysis is performed using a modified version of the KVH method [Kuik et al, 1988]. These same analysis algorithms have been used by all TRIAXYS sensor models up to the present g3 release.

The original TRIAXYS wave sensor utilized three accelerometers, three rate gyros, a fluxgate compass, and the proprietary TRIAXYS processor. The TRIAXYS processor was based on AXYS' WatchMan100 payload used on other AXYS systems in marine environments. In 2010, TRIAXYS underwent a processor upgrade, moving from the legacy WatchMan100 processor to the low powered, more powerful WatchMan500™ (WM500). The new sensor, known as the TRIAXYS Next Wave (TRIAXYS NW). In late 2012, the TRIAXYS NWII was released by migrating from discrete components for the accelerometers and rate gyros to a microelectromechanical systems (MEMS) sensor while retaining the original discrete compass. The TRIAXYS NWII resulted in a reduced footprint with less power consumption. Released in 2016, the TRIAXYS underwent a complete revamp while retaining the original design concept and algorithms. The MEMS and Compass were replaced with a single MEMS unit with integrated magnetometers. The processer and supporting hardware are upgraded; this hardware upgrade results in new processing features as well as reduced footprint and power consumption, while maintaining the trusted accuracy of the TRIAXYS product line.

III. TRIAXYS G3 ADVANCEMENTS AND FEATURES

A. *Spectral Statistic Ranges*

The TRIAXYS g3 has 2 additional data sets beyond the standard full frequency spectra wave statistics. These data sets contain the same spectra based wave statistics as the standard data set with the advantage of having independently configured frequency ranges. This allows the unique opportunity to analyze real time spectra based wave statistics across various ranges of interest for a more sophisticated understanding of the sea state without involving the full directional spectra.

B. *Data Structure/Messaging*

The data messages are redesigned in the TRIAXYS g3 which utilize Protocol Buffers. Protocol Buffers allow the implementation of flexible, extensible and efficient serialized data. To further reduce message sizes, the directional spectra messages are reformatted utilizing data compression techniques. The directional spectra is populated in 3 different messages, small, medium and large, depending on the granularity of frequency bands vs the bandwidth requirements. Table I depicts the data message list of the TRIAXYS g3 along with the typical message size in bytes. The Directional Spectra messages are predefined frequencies spanning 0.03 to 0.64 Hz. The content of the Directional Spectra message contains the Energy along with the A1, B1, A2, B2 Fourier coefficients for each frequency.

TABLE I. TRIAXYS G3 DATA MESSAGES

Message	Length (B)	Num. Freq.
Wave Statistics	159	-
Directional Spectra (small)	342	32
Directional Spectra (medium)	630	64
Directional Spectra (large)	1163	123

C. *Moving Window Processing*

In TRIAXYS wave sensors, the output rate of processed wave data has been limited to the sampling duration required per interval; for example, a TRIAXYS wave sensor is configured to measure motion data for a 20 min period, the highest output rate that the processed wave statistics and directional spectra data could be transmitted is every 20 min. This was imposed due to the limited processing ability of the sensor. The TRIAXYS g3 has removed this limitation by implementing a moving window sampling period. This enables the sensor to utilize a configurable output rate that is independent to the sampling duration. The TRIAXYS g3, for example, can output the fully processed wave data of the last 20 min of sampling data every 1 min allowing the TRIAXYS g3 to provide continuous operational updates on sea states.

D. *Compact Size*

The TRIAXYS g3 sensor utilizes a new form factor and aluminum enclosure with the following dimensions: 8.5cm (L) x 8.0cm (W) x 3cm (H) with an overall weight of 150g. These dimensions are illustrated in Fig. 1.

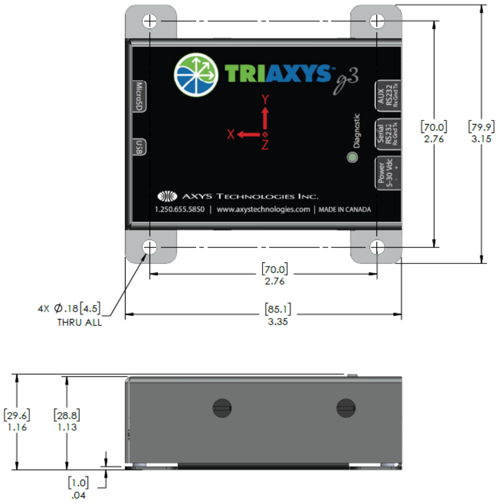

Fig. 1. TRIAXYS g3 Dimensions

For harsh environments the TRIAXYS g3 is mounted in the original TRIAXYS NWII enclosure - a non-corrosive, UV stabilized, EMC shielded, intrinsically safe, FRP impregnated enclosure with IP66 (NEMA 4X) classification. Fig. 2 illustrates the size differences between the TRIAXYS g3 and the NWII.

Fig. 2. TRIAXYS g3 vs. TRIAXYS NWII – Physical Size

E. Power

The TRIAXYS g3 utilizes a new sensor package and supporting electronics. These key elements result in an overall power reduction of approximately 40% when compared to the TRIAXYS NWII sensor. This power comparison is calculated based on an interval by interval basis, for example a 20 min sampling period with a single set of output parameters.

Table II depicts the voltage range and power consumption of the TRIAXYS g3. The daily energy usage of the TRIAXYS g3 vs the TRIAXYS NWII is depicted in Table III. The systems are configured under a typical sampling regime of - Interval/Duration: 30min/20min.

TABLE II. TRIAXYS G3 POWER REQUIREMENTS

Parameter	Value	Units
Min. Voltage	5.0	V
Max. Voltage	35.0	V
Power	1.0	W

TABLE III. TRIAXYS DAILY POWER CONSUMPTION (30MIN/20MIN)

Parameter	Wh/Day	Ah/Day
NW	56.16	4.68
NWII	28.32	2.36
g3	17.33	1.44

IV. TRIAXYS G3 VALIDATION TRIALS

Over the years, AXYS has established sensor validation protocols to ensure that any changes to the TRIAXYS hardware/firmware design are characterized against past system performance on both calibration apparatus and in the oceanic environment against other standards. One of the new techniques used to validate the TRIAXYS g3 has been to co-locate both the TRIAXYS g3 and TRIAXYS NWII sensors on the same platform. This comparison method was made more feasible through the advancements in reduced energy consumption and size of the new sensor.

A. Motion Swing

The TRIAXYS g3 has been tested using a motion swing which imposes a controlled environment with known wave height and variable wave periods. This calibration apparatus is based on a 2.00 m mechanical swing, inducing a theoretical perfect sinusoidal wave pattern. The wave periods tested range from 5 to 25s in 5s increments for 20 min durations. During the mechanical motion test the sensor is aligned along the axis under stress. The compass values are set to 0 to eliminate magnetic errors which would be caused by the ferric material of the swing; therefore the expected direction is 0° with some variability based on the physical alignment of the sensor and the swing. Table IV depicts the swing test results of the TRIAXYS g3 sensor with serial number TAS08008 – the average wave periods (Tavg) and heights (Havg) along with the measured mean direction is shown.

TABLE IV. TAS08008 – MOTION SWING RESULTS

Calibration Period (s)	Tavg (s)	Havg (m)	Mean Direction (deg)
25.17	25.10	2.01	0.0
20.11	20.00	2.00	0.3
15.10	15.10	2.00	0.3
10.03	10.00	2.00	0.3
5.01	5.00	1.99	0.3

B. Sea Trials

The TRIAXYS g3, to date, has been deployed in 3 sea trials with varying ocean conditions. The test platform was a standard TRIAXYS 1m directional wave buoy with both TRIAXYS NWII and TRIAXYS g3 sensors integrated into a single payload. The co-located sensors gives the unique opportunity to directly compare wave sensing technologies on a single platform removing any biases from independently moored platforms. The study design follows similar procedures WMO-JCOMM is using for the evaluation of different Wave Measurement technologies in the PP-WET Study. The wave sensors were configured to sample motion data for 20 minute durations with variable intervals.

1) West Coast Vancouver Island

a) Florencia Bay

This system was deployed at a mean sea level (MSL) of 30m - for a 1 month deployment (Sept/15) located at coordinates 48.95398, -125.61247 (deg). This trial yielded 1313 comparable data records. The sea states observed in this trial period are shown in Table V.

TABLE V. FLORENCIA BAY TRIAL SEA CONDITIONS

Analysis	Parameter	Min	Max
Zero Crossing	Hmax (m)	0.98	6.31

	Hav (m)	0.34	2.45
	Hsig (m)	0.57	3.72
	H10 (m)	0.79	4.68
	Tsig (s)	5.44	12.62
	Tav (s)	3.84	8.52
	T10 (s)	5.40	15.75
Spectral	Hm0 (m)	0.69	3.76
	Te (s)	5.67	14.65
	Tmean(s)	4.11	8.08
	TP (s)	4.76	20.00

b) Port Renfrew

This system was under test for a 2 month deployment (November 6/15-January 11/16) at the following coordinates: 48.5358704, -124.4887027 (deg). This deployment yielded 3155 comparable records at a MSL of 25m. The sea states observed in this trial period are shown in Table VI.

TABLE VI. PORT RENFREW TRIAL SEA CONDITIONS

Analysis	Parameter	Min	Max
Zero Crossing	Hmax (m)	0.62	11.48
	Hav (m)	0.23	4.59
	Hsig (m)	0.35	6.93
	H10 (m)	0.44	8.35
	Tsig (s)	3.38	16.02
	Tav (s)	2.77	12.99
	T10 (s)	3.58	19.01
Spectral	Hm0 (m)	0.42	7.00
	Te (s)	4.32	16.61
	Tmean(s)	2.95	12.69
	TP (s)	3.57	28.57

2) German North Sea (FINO 1)

The study was conducted in the German North Sea near the FINO 1 Research Platform. A TRIAXYS buoy fitted with a g3/NWII sensor was deployed for a 3 month time period at the coordinates: 54.5358704, 6.4887027 (deg) at a MSL of 30m. This deployment yielded 1870 records for comparison. The sea states observed in this trial period are shown in Table VII.

TABLE VII. FINO1 TRIAL SEA CONDITIONS

Analysis	Parameter	Min	Max
Zero Crossing	Hmax (m)	0.65	16.61
	Hav (m)	0.27	4.30
	Hsig (m)	0.41	6.62
	H10 (m)	0.51	8.05
	Tsig (s)	2.76	10.81
	Tav (s)	2.35	8.83
	T10 (s)	2.77	15.60
Spectral	Hm0 (m)	0.43	6.87
	Te (s)	3.29	18.46
	Tmean(s)	2.54	9.32
	TP (s)	2.53	28.57

C. Sea Trials Sensor Validation Analysis

1) Wave Statistics

The wave statistics comparison is split into 2 groups: the Heave, zero crossing, based wave parameters and the spectra, frequency, based parameters. Where n is the number of samples, $\hat{y}_t$ and y_t are the TRIAXYS g3 and NWII measurements respectively the following calculations are depicted in the following tables:

- Coefficient of determination (r^2): The square of the Pearson product-moment correlation coefficient r between two variables. [3]

- Mean Error (ME): The average of the error values, matches unit of parameter, matches unit of parameter, meters (m) for heights and seconds (s) for periods.

$$ME = \frac{1}{n}\sum_{t=1}^{n} \hat{y}_t - y_t \tag{1}$$

- Mean Absolute Error (MAE): The average of the absolute values of the errors, matches unit of parameter, meters (m) for heights and seconds (s) for periods.

$$MAE = \frac{1}{n}\sum_{t=1}^{n} |\hat{y}_t - y_t| \tag{2}$$

- Mean Percent Error (MPE): The average errors in percentage - Average Bias (%).

$$MPE = \frac{100}{n}\sum_{t=1}^{n} \frac{\hat{y}_t - y_t}{y_t} \tag{3}$$

- Root Mean Square Error (RMSE): The sample standard deviation of the errors, matches unit of parameter, meters (m) for heights and seconds (s) for periods.

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} (\hat{y}_t - y_t)^2}{n}} \tag{4}$$

Table VIII depicts the time series, heave based, parameter errors when comparing the TRIAXYS g3 vs TRIAXYS NWII. The error calculations illustrate the differences in bias and variance between the two sensors.

The r^2 parameter of the wave heights in all deployments is >0.99, showing a tight correlation between the two sensors. The ME illustrates an average bias in the Havg and Hsig parameters of 0.01m and the Tavg and Tsig not exceeding 0.13s. The MAE of the Havg and Hsig parameters do not exceed 0.01m, with a maximum difference in Hmax to be 0.04m. The periods show similar results with the MAE of the Tavg and Tsig parameters not exceeding 0.17s. The RMSE has a maximum Havg and Hsig value of 0.02m with a maximum Tavg and Tsig value of 0.2s. These differences equate to an excellent agreement between the two wave sensing technologies and that the TRIAXYS g3 is capable of measuring the equivalent heave based wave statistics as the TRIAXYS NWII.

TABLE VIII. TRIAXYS G3 VS NWII – ZERO CROSSING BASED WAVE STATISTIC ERRORS

Florencia Bay	**Havg (m)**	**Tavg (s)**	**Hsig (m)**	**Tsig (s)**	**H1_10 (m)**	**T1_10 (s)**	**Hmax (m)**
r^2	0.9974	0.9710	0.9992	0.9781	0.9991	0.9785	0.9962
g3 ME (m) (s)	0.00	-0.13	0.00	-0.08	0.01	-0.05	0.02
g3 MAE (m) (s)	0.01	0.15	0.01	0.13	0.01	0.17	0.04
g3 MPE (%)	-0.22	-2.21	0.26	-0.94	0.39	-0.51	0.65
g3 RMSE (m) (s)	0.02	0.19	0.01	0.20	0.02	0.25	0.05
Renfrew	**Havg (m)**	**Tavg (s)**	**Hsig (m)**	**Tsig (s)**	**H1_10 (m)**	**T1_10 (s)**	**Hmax (m)**
r^2	0.9991	0.9961	0.9997	0.9969	0.9997	0.9940	0.9991
g3 ME (m) (s)	0.00	0.01	0.00	0.01	0.00	0.01	0.00
g3 MAE (m) (s)	0.01	0.09	0.01	0.10	0.01	0.13	0.02
g3 MPE (%)	0.02	0.17	0.01	0.17	-0.01	0.14	-0.06
g3 RMSE (m) (s)	0.01	0.12	0.01	0.14	0.02	0.20	0.03
FINO 1	**Havg (m)**	**Tavg (s)**	**Hsig (m)**	**Tsig (s)**	**H1_10 (m)**	**T1_10 (s)**	**Hmax (m)**
r^2	0.9994	0.9969	0.9998	0.9982	0.9996	0.9955	0.9938
g3 ME (m) (s)	0.00	0.00	-0.01	0.00	-0.01	0.00	-0.01
g3 MAE (m) (s)	0.01	0.05	0.01	0.04	0.01	0.05	0.03
g3 MPE (%)	-0.17	0.04	-0.20	0.05	-0.23	0.00	-0.26
g3 RMSE (m) (s)	0.02	0.06	0.02	0.05	0.03	0.09	0.13

The spectral, frequency and energy, based parameter errors are depicted in Table IX. The Hm0, Te and Tmean parameters have excellent r^2 values being >0.99. The ME shows little bias in Hm0 with a value of 0.01m and the Te and Tmean values resulting in a bias < 0.08s. Similarly with the heave based wave statistics the TRIAXYS g3 is tightly coupled with the TRIAXYS NWII. Showing that the g3 can represent the equivalent spectral based wave statistics as the TRIAXYS NWII. The mean direction of the Florencia Bay deployment shows excellent correlation between the two heading values of the sensors. With a mean absolute error of 1.75°.

TABLE IX. TRIAXYS G3 VS NWII – SPECTRAL BASED WAVE STATISTIC ERRORS

Florencia Bay	**Hm0 (m)**	**Te (s)**	**Tmean (s)**	**Tp (s)**	**Tp5 (s)**	**Mean Direction (deg)**	**Mean Spread (deg)**
r^2	0.9998	0.9980	0.9972	0.9422	0.9972	0.9932	0.9534
g3 ME	0.01	-0.03	-0.08	-0.01	-0.02	0.67	-1.23
g3 MAE	0.01	0.05	0.08	0.13	0.07	1.75	1.24
g3 MPE (%)	0.33	-0.37	-1.28	0.37	-0.21	0.35	-3.17
g3 RMSE	0.01	0.07	0.09	0.93	0.17	2.35	1.65
Renfrew	**Hm0 (m)**	**Te (s)**	**Tmean (s)**	**Tp (s)**	**Tp5 (s)**	**Mean Direction (deg)**	**Mean Spread (deg)**
r^2	1.0000	0.9996	0.9999	0.9772	0.9986	0.7518[a]	0.9713
g3 ME	0.00	0.01	0.01	0.00	0.00	6.64[a]	0.05
g3 MAE	0.00	0.02	0.01	0.05	0.05	12.33[a]	0.72
g3 MPE (%)	-0.02	0.10	0.10	0.13	0.04	3.29[a]	0.14

g3 RMSE	0.01	0.04	0.02	0.48	0.11	13.93[a]	1.00
FINO 1	**Hm0 (m)**	**Te (s)**	**Tmean (s)**	**Tp (s)**	**Tp5 (s)**	**Mean Direction (deg)**	**Mean Spread (deg)**
r^2	0.9995	0.9968	0.9997	0.9890	0.9988	0.8677[a]	0.9939
g3 ME	-0.01	0.01	0.00	0.00	0.00	-4.87[a]	0.08
g3 MAE	0.01	0.02	0.01	0.03	0.02	7.04[a]	0.34
g3 MPE (%)	-0.19	0.17	0.00	0.02	0.00	49.97[a]	0.25
g3 RMSE	0.02	0.07	0.02	0.22	0.06	23.95[a]	0.47

[a.] Large Errors due to Magnetic Calibration error.

A time series comparison of the Hm0 data parameter of the Renfrew deployment is depicted in **Error! Reference source not found.**. Fig.4 illustrates the Tmean data parameter. These same data sets are displayed in Fig. 5 and Fig. 6. utilizing correlation plots. These figures show the excellent correlation between the TRIAXYS g3 and NWII.

The graphs represented in the following figures are only shown for the Renfrew deployment. The Florencia Bay and FINO 1 deployments have been omitted for brevity.

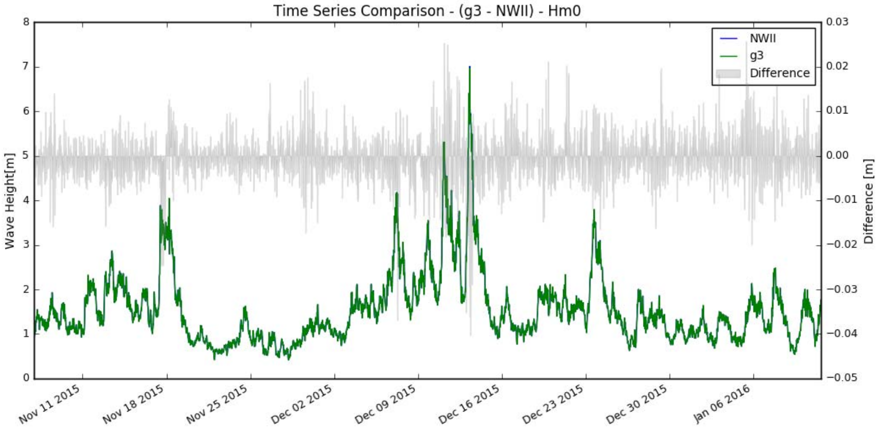

Fig. 3. Renfrew - Hm0 (m) - Time Series Comparison

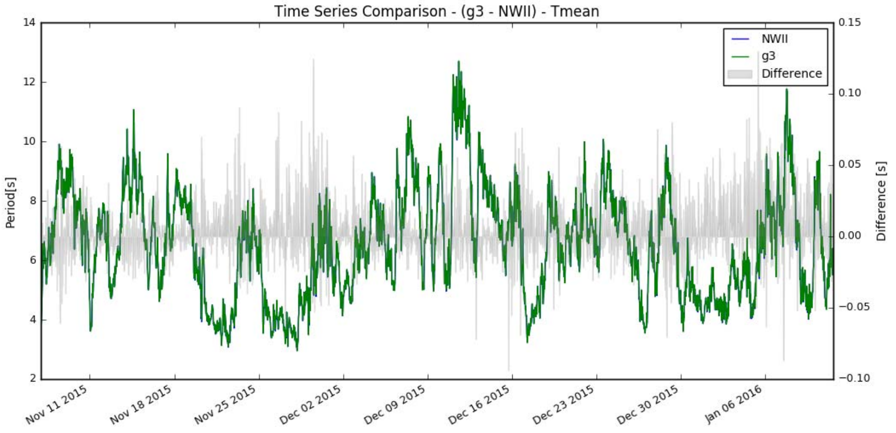

Fig. 4. Renfrew - Hm0 (m) - Time Series Comparison

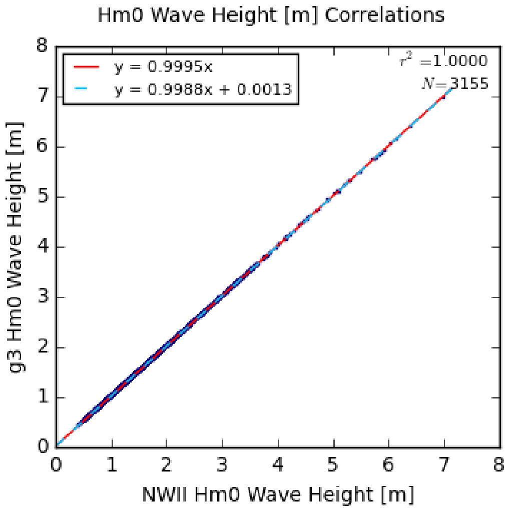

Fig. 5. Renfrew - Hm0 - Correlation

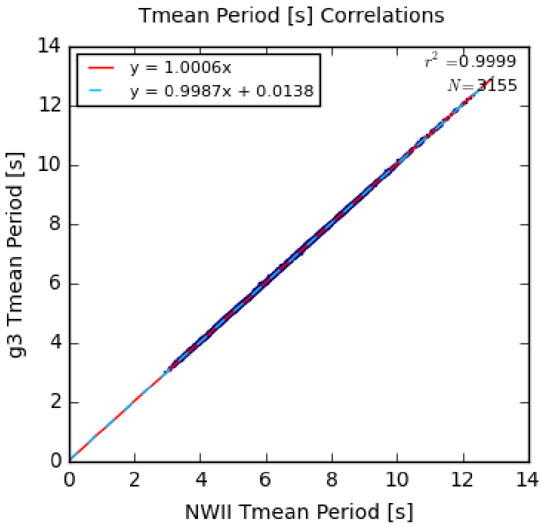

Fig. 6. Renfrew -Tmean - Correlation

It can be seen in Table IX that both the Port Renfrew Trial and the FINO1 trial that there is significant errors in the Mean Direction data parameter. These errors are due to both the TRIAXYS NWII and the TRIAXYS g3 internal compasses not being magnetically calibrated correctly prior to deployment; therefore higher errors are present when comparing these data parameters. On recovery the compasses of the two sensors were compared, recalibrated and compared again.

Fig. 7. illustrates the correlation between the TRIAXYS g3 and the NWII compass values from the Port Renfrew Deployment. It can be seen that the values compare poorly which leads to the expected errors shown in Table IX.

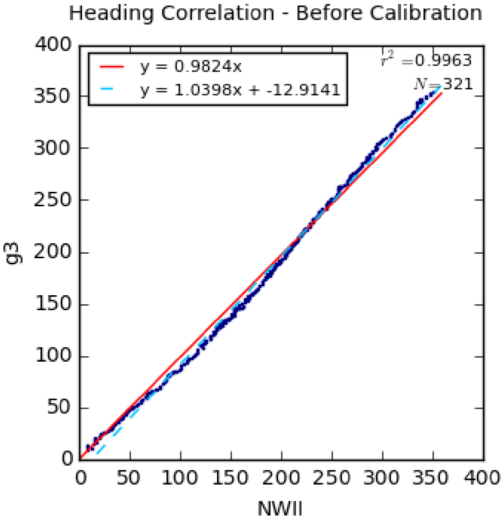

Fig. 7. Renfrew Compass Comparison – Deployed

Fig. 8. depicts the same comparison as Fig. 7. after the compasses of both sensors have been calibrated within the buoy. As expected the 2 values are tightly coupled and should resolve the direction errors represented in IX.

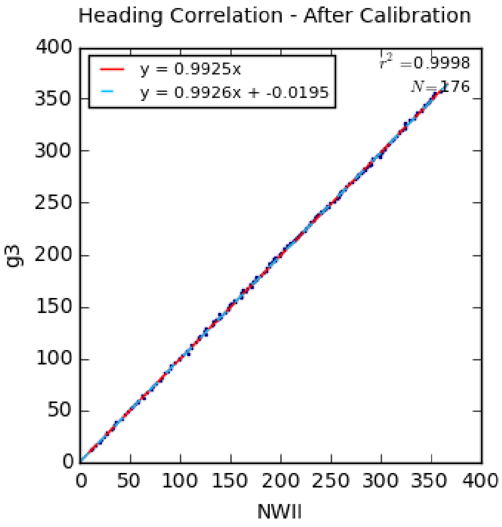

Fig. 8. Renfrew Compass Comparison – Calibrated

The Florencia Bay deployment, where both sensors were magnetically calibrated correctly, is depicted in Fig. 9. With an r^2 value >0.99, this shows that with a correct compass calibration, the directions reported from the TRIAXYS g3 are equivalent to the TRIAXYS NWII.

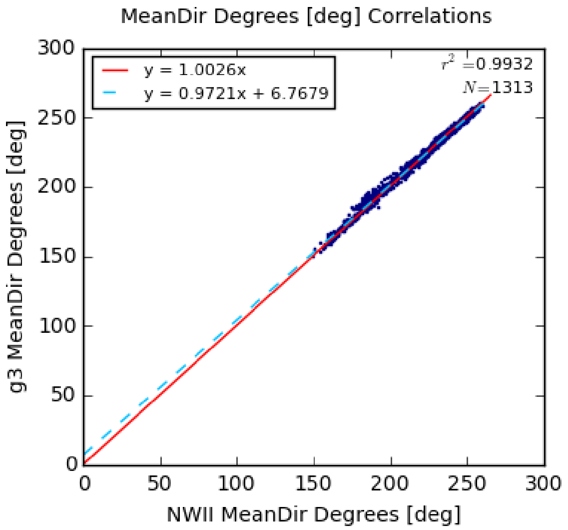

Fig. 9. Florencia Bay – Mean Direction (deg)

2) *Energy Spectra*

The wave spectra can be compiled into bins which are defined by energy and frequency. The following wave spectra figures are modelled after the CDIPS waveEVALTool [2] and illustrate 3 sets of information:

- Number of Observations – The number of measurements detected by the TRIAXYS g3 sensor in the specified bin throughout the deployment.
- Height Average Bias – The average bias in wave height for each specified bin of the TRIAXYS g3 referenced to the TRIAXYS NWII. Equivalent to the MPE equation in the wave statistics analysis.
- Height NRMSE Bias Removed – The normalized root-mean-square error of the wave heights with the bias removed is the average error percentage of the errors against the average errors of the bin.

$$MSE = \frac{\sum_{t=1}^{n} (\hat{y}_t - y_t)^2}{n} \qquad (5)$$

$$NRMSE_{BiasRemoved} = 100\,\frac{\sqrt{MSE - ME^2}}{\overline{yt}} \qquad (6)$$

The following graphs depict the wave spectra comparison of the Renfrew deployment. Similarly with the wave statistics, only the Renfrew data sets are presented for brevity.

The dotted line represents the theoretical wave spectra with an Hs of 20m [2]. The left axis depicts a logarithmic scale of the energy in meters squared (m^2) while the right axis shows the wave height in meters (m). The x or bottom axis represents the scale for the frequencies and periods.

The number of observations are depicted in Fig. 10. The darker shaded bins represent a higher observation count as described by the colour bar. The comparison graphs, Fig. 10. and Fig. 11, are filtered to a minimum observation count of 10. This was chosen to represent a significant sample size to reflect the default settings used in the waveEVALTool.

The average wave height bias depicted in Fig. 11 show an excellent comparison with little to no bias between the TRIAXYS g3 and the TRIAXYS NWII. There are homogenous errors, approaching 0%, across significant energies and frequencies. The NRMSEBiasRemoved of the Renfrew deployment is shown in Fig. 12 where throughout the wave spectrum the two sensors show excellent comparisons with the significant energies and frequency bins with a results of <2%.

In the bottom left of the figures some differences are apparent; however these are deemed insignificant. In this region of the graphs the sensors are approaching a static position; as such the signal to noise ratio of the motion data is reduced. Resulting in greater differences between the two sensors as the low signal characteristics of the sensors are inherently different. The energy magnitude in these bins is negligible when compared to the total energy of a complete wave spectra, hence the resulting wave statistics are not affected.

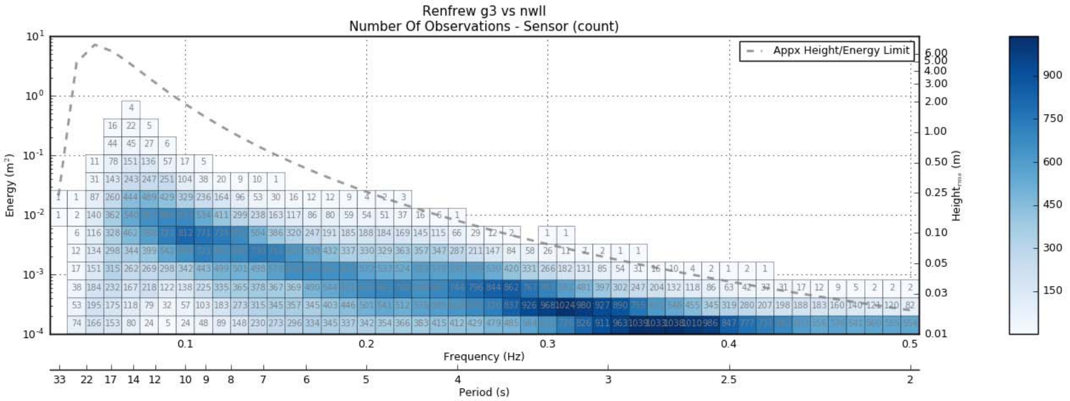

Fig. 10. Renfrew - Wave Spectra - Number of Observations

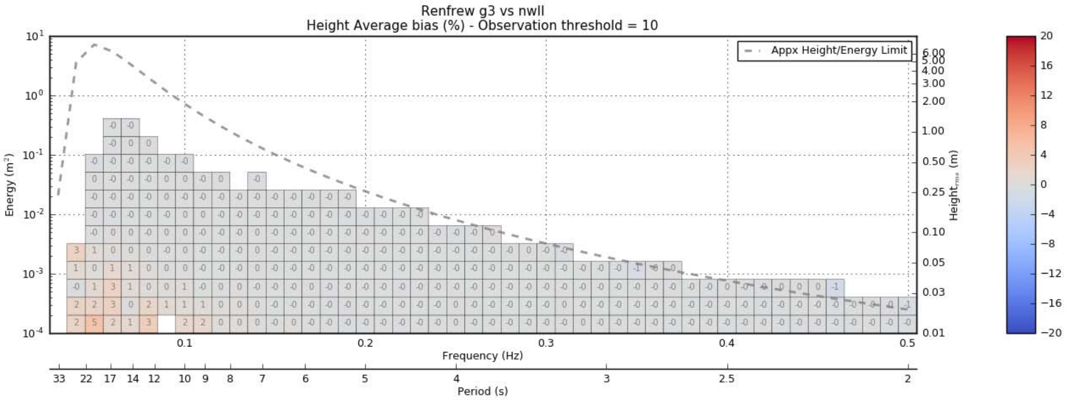

Fig. 11. Renfrew - Wave Spectra - Wave Height Average Bias (%)

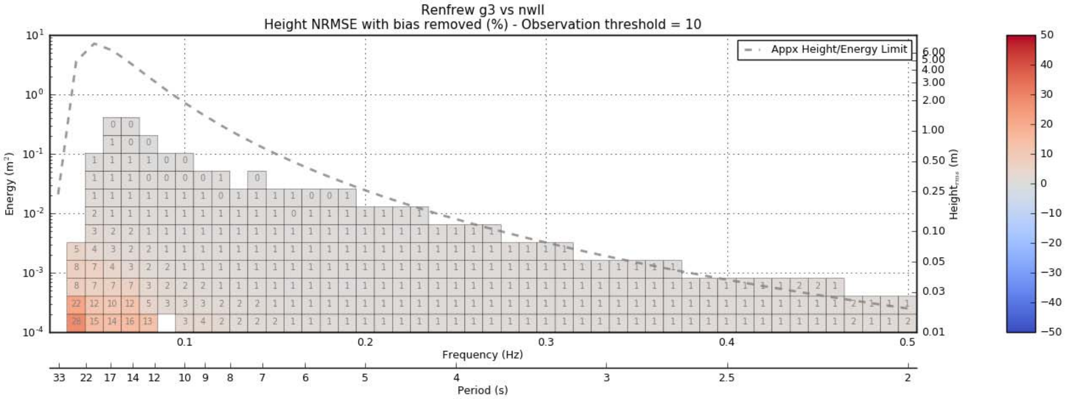

Fig. 12. Renfrew - Wave Height NRMSE with Bias Removed (%)

V. SUMMARY

The TRIAXYS g3 wave sensor implements a sophisticated microcontroller which enables several functional upgrades: frequency partitioning of Spectral wave statistics, optimized message definitions and the ability to produce wave data outputs at an increased rate utilizing a moving window. A state of the art motion sensor is implemented eliminating a need for a discrete compass. This facilitates reduction in overall sensor power usage, physical footprint and sensor complexity.

The typical wave height and period parameters: Havg, Hsig, Hm0, Tavg, Tsig, Te and Tmean of the TRIAXYS g3 show excellent correlation with the TRIAXYS NWII. The r^2 values all exceed 0.99, with little variance and bias. The wave heights MAE does not exceed 0.01m with the Hmax MAE not exceeding 0.04m. The wave spectra reported by the TRIAXYS g3 compares with a typical error approaching 0% when compared to the TRIAXYS NWII across significant energies and frequencies. The TRIAXYS g3 measures waves and sea states with the equivalent accuracy of the TRIAXYS NWII wave sensor.

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