TRIAXYS Next Wave II Directional Wave Sensor

The Evolution of Wave Measurements

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Abstract— The TRIAXYS™ Directional Wave Sensor, manufactured by AXYS Technologies Inc. (AXYS), has been a leading technology for directional wave measurements since its inception in the late 1990's. Product improvements have been made over the years related to the onboard micro-processor, but the technology surrounding the acquisition of raw motion data for analysis of vertical displacement, and north and east velocities in six degrees of freedom has not changed, until now. The latest release of the sensor, the TRIAXYS Next Wave II Directional Wave Sensor, will utilize a new inertial sensor to capture the raw motion data for wave analysis using the same techniques that have made the sensor a world leading technology. The sensor will carry additional features including a smaller size, lower power requirements, and improved ranges and accuracies.

I. Introduction

Moored buoys equipped with 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, precise 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.

Wave data are often used for operational purposes, climate studies, and research and development initiatives related to ocean stewardship. It is common for climate studies, as well as R&D studies, to require reliable wave data for a minimum period of one year. This need mandates an easy to use system that can be readily deployed and operated for the duration of the project. Wave data used for operational purposes require the data acquisition system to be long lasting with minimal need of maintenance or servicing, such as calibration.

This paper will discuss AXYS Technologies' TRIAXYS™ wave sensor and how it has evolved into the world leading sensor for the acquisition of wave data.

II. TRIAXYS Legacy

The Canadian Hydraulics Centre (CHC) of the National Research Council (NRC) of Canada and AXYS jointly developed the TRIAXYS Directional Wave Buoy in response to the small sample of available data on the directional characteristics of prototype waves. The need arose from the increase in laboratory testing of coastal processes and structures under multidirectional waves, and the resulting need to measure the structure performance in these wave environments.

The TRIAXYS Directional Wave Buoy is a rugged, easy to use system that accurately measures wave height, period and direction. The original TRIAXYS wave sensor inside the buoy used three accelerometers, three rate gyros, a fluxgate compass, and the proprietary TRIAXYS processor. The TRIAXYS processor is based on AXYS' WatchMan100 payload used on other AXYS systems in marine environments.

The TRIAXYS buoy was not the first wave buoy available on the market. However, it did include innovative, differentiating features including:

- Full frequency domain and time domain wave analyses can be performed on the buoy
- Both processed data and raw data can be stored on the buoy
- Spectral data and wave statistics can be transmitted from the buoy using a variety of telemetries (VHF, cellular, satellite)
- Solar power providing power supply for 3 – 5 years based on typical deployment characteristics following recommended maintenance procedures
- Protective dome housing solar panels, antenna, light and IR/Bluetooth offers safety and ease of handling in deployment and recovery
- Configuration of the buoy's functions, including sampling duration and interval, transmission intervals, and storage options

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Fig. 1. *TRIAXYS Directional Wave Buoy*

The TRIAXYS wave sensor was also made available as a standalone product to be used as a controllable sensor by other data loggers. The TRIAXYS sensor enclosure contains the three accelerometers and the three rate gyros, the fluxgate compass for magnetic orientation and the TRIAXYS WatchMan100 processor. All components used in the system are precision solid state sensors without any moving parts.

Fig. 2. *TRIAXYS Directional Wave Sensor*

The TRIAXYS sensor is a low power device which is easily configurable and controlled utilizing a versatile instruction set. The sensor can run in a self controlled mode where little to no interaction to the sensor is required, or controlled externally via the power and communication port. The communication interface is a simple 3 wire RS-232 interface, requiring RX, TX and GND allowing the device to be connected to a wide array of possible host controllers. The TRIAXYS wave sensor's WatchMan100 processor has a built in data logger with a capacity of up to 32GB of data. The data logged is highly configurable based on the user's unique logging requirements.

A. *Software*

The TRIAXYS wave sensor provides zero-crossing statistics, spectral statistics and both directional and non-directional wave spectra from the measurements acquired from the wave conditions. The wave height and wave period statistics include Hmax, H1/10, H1/3, Havg, Tmax, T1/10, Tavg, Tz, Tp, Ts, Mean Direction, Mean Spread, etc. A typical wave sample of 20 – 25 minutes provides time series data that is processed to determine the above mentioned statistics and spectra.

The software used onboard the TRIAXYS sensor includes a motion analysis algorithm to analyze the measured data from the accelerometers, rate gyros, and the compass, and an algorithm to resolve the directional and non-directional spectra of sea state from the previously analyzed data.

1) *Motion Analysis*

The buoy motion is measured in six degrees of freedom by three strap down accelerometers and three strap down rate gyros. The accelerometer measurements include earth gravity components along the x, y, and z axes of the buoy. The rate gyros measure the 3-D rotation of the buoy resolved along the instantaneous positions of the x, y, and z axes. AXYS 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. By using full non-linear equations of motion, accurate motion data can be obtained for extreme conditions with large roll and pitch angles. The directional wave analysis is computed using the heave displacement as well as the surge and sway velocity components. The compass allows for the surge and sway velocities to be resolved in the north and west directions.

The motion analysis software is based on the MOTAN inertial motion measurement system developed by the CHC to measure the motions of ship models and other floating structures in wave basins and towing tanks. Computer simulations and tests conducted in a multi directional wave basin with a QUALISYS optical tracking system for comparison have provided verification of the MOTAN software. The results show a typical accuracy of 1mm for surge, sway, and heave and 0.1 degrees for roll, pitch and yaw motions.

2) *Wave Analysis*

The wave analysis software used in the TRIAXYS sensor is based on GEDAP software, originally developed for internal use at CHC [2]. The software is now widely used around the world for random wave generation and analysis in basins including artificially generated multidirectional waves.

A wave analysis is run directly on the TRIAXYS™ sensor. 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 is computed the non-directional wave spectrum using FFT procedures along with various spectral parameters including Hmo, Tp, and Tp5, where Tp5 is the peak wave period computed by the Read Method [3]. Further directional wave analysis is performed using a modified version of the KVH method [Kuik et al, 1988]. It first computes the cross spectra of wave elevation z(t) and the north and west velocities u(t) and v(t) and then computes the first four Fourier coefficients A1(f), B1(f), A2(f) and B2(f) of the directional spreading function D(f,0). These coefficients are then used to compute the mean wave direction 0m(f) and the directional spreading width σ0(f) as functions of frequency. The final directional wave analysis is performed on shore using AXYS software.

The four Fourier coefficients A1(f), B1(f), A2(f) and B2(f) are transmitted to shore and received by the software which then performs the directional wave analysis using the Maximum Entropy Method (MEM) [Neogu et al, 1987] to obtain the directional wave spectrum S(f,0). TRIAXYS can also be configured to transmit the Heave North East (HNE) time series data file if users prefer to apply a different method for realizing directional wave analysis.

B. TRIAXYS with Current Profiling (ADCP)

In 2004, AXYS, together with Nortek of Norway, collaborated on the development of a custom ADCP head to fit in the TRIAXYS buoy hull. This custom Aquadopp head would allow for ocean currents to be profiled from the wave buoy to a depth of 40m using the 600KHz profiler.

During the summer months of 2004, the TRIAXYS buoy equipped with the Nortek Aquadopp 600KHz profiler was deployed for a study compared with two bottom mounted ADCP's – a Nortek Aquadopp 600KHz Profiler and a Teledyne RDI 300KHz ADCP. The systems were deployed off Ucluelet, B.C. near 48° 55.50'N 125° 34.14'W. The bottom mounted ADCP's were spaced 100m apart at a depth of 45m [4].

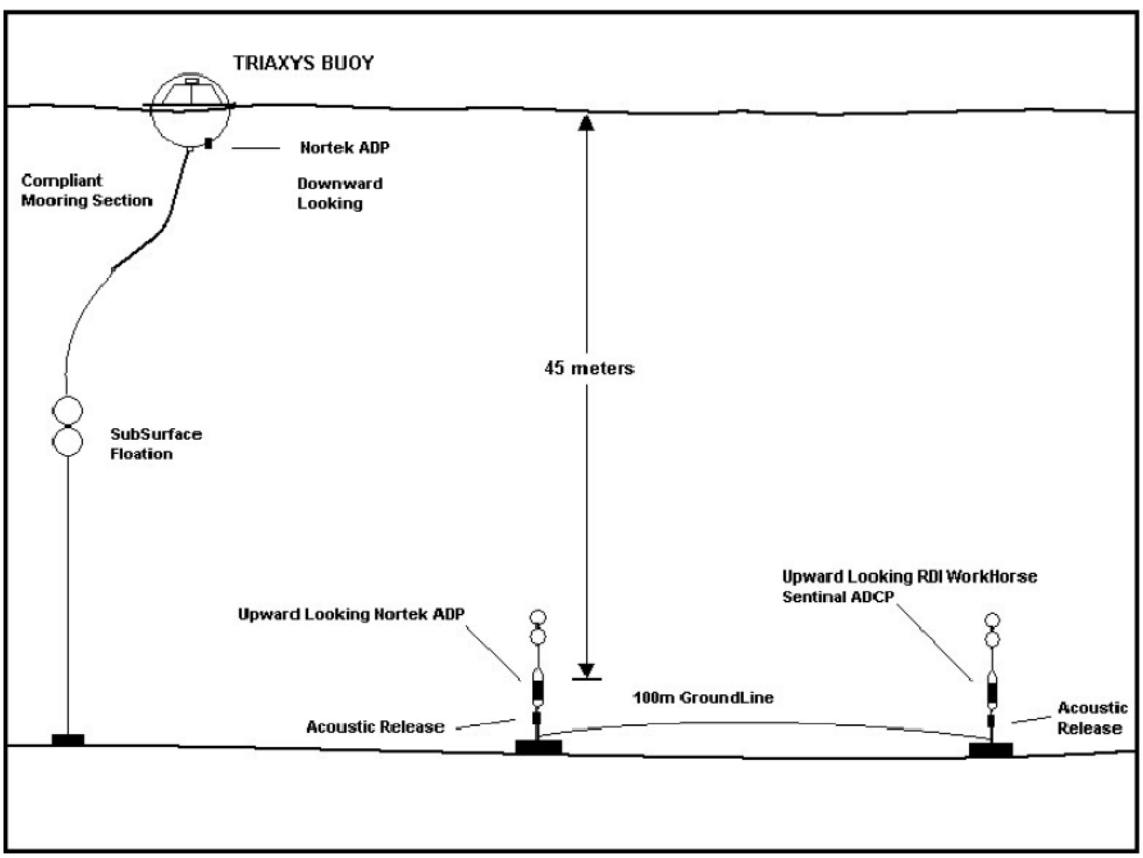

Fig. 3. *Deployment of TRIAXYSwith Currents buoy and two bottom-mounted ADCP's*

The results of the study brought forth the following conclusions:

- The TRIAXYS with Currents buoy velocity magnitudes agreed with the bottom mounted profilers within 0.04 – 0.05 m/s, with the average difference of about 0.04 m/s
- The TRIAXYS with Currents buoy direction measurements agreed with the bottom mounted profilers to within 5 degrees, with the average difference being less than within 3 degrees
- The wave heights (to 2.4m Hs) experienced during the trial did not affect the current velocity or direction data between the TRIAXYS with Currents buoy and the bottom mounted profilers
- The downward looking TRIAXYS with Currents (600KHz ADCP) buoy had a maximum range on the order of 30m
- Differences in measurements identified in the study may be due to:
    - Environmental differences experienced near the surface and at the seabed are expected, and are caused by acoustic side lobe contamination
    - Site specific differences (temporal, spatial)
    - Instrument errors
    - Mooring induced velocities

The TRIAXYS with Currents buoy gained quick market acceptance and soon became a preferred method of measuring wave and current parameters due to its ease of operation and handling. The buoy is now offered with multiple profilers – the Nortek 2MHz, 1MHz, 600KHz, 400KHz and the Teledyne RDI 600KHz. The RDI ADCP can also be configured to use the RDI bottom tracking feature. All profilers are capable of being configured as per the normal manufacturer profilers.

C. TRIAXYS Next Wave

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) provided the market with the following improvements in wave measurements:

- Additional I/O allowing multiple telemetry systems to be used on the TRIAXYS buoy
- Additional I/O allowing the TRIAXYS sensor to act as a controller/datalogger over and above the main purpose of measuring directional waves
- Analogue, digital, RS-232, RS-422, RS-485, SDI-12, CANBUS, PUCK
- The use of AXYS' Data Management System (DMS) for enhanced viewing of sensor or buoy diagnostics as well as remote configuration from your desktop PC
- Increased data storage up to 32GB
- The WM500 allows the sensor to perform continuous wave sampling, where the sensor continues to sample waves while processing the previously measured sample and transmitting the wave data

III. TRIAXYS NEXT WAVE II

In late 2012, AXYS, as part of its continued R&D efforts on new and existing technologies, began reviewing potential improvements to the TRIAXYS NW sensor. The goal of the R&D initiative was to bring to market a more compact, lower powered solution that could offer a smaller footprint and power draw to already congested wave and metocean buoys that struggle to balance space and power with operational sampling regimes. Extensive reviews of inertial sensors to measure motion, consolidating onboard electronics and new enclosures to house the intelligence resulted in a new sensor configuration that, when married with the WatchMan500, provides the market with a new wave sensor to be used worldwide. The new features of the TRIAXYS Next Wave II (TRIAXYS NW II) that are most important and relevant to the measurement of waves are: 1) the low power requirements, 2) the small footprint, and 3) the resulting sensor specifications.

A. Power

The TRIAXYS NWII utilizes new sensors and electronics, resulting in a 50% reduction in power consumption when compared with the TRIAXYS NW. The TRIAXYS NWII power input is 12VDC nominal (10-18VDC compatible). Low power and sleep modes are available; with the default sampling regime, 20min sample every 30min, the TRIAXYS NWII consumes 2.36 Ah/day (at 12VDC) or 28.32 Wh/day. A comparison of the power budget of the TRIAXYS NW and TRIAXYS NWII is shown in table 1 below.

TABLE I. POWER BUDGET COMPARISON BETWEEN NW AND NW II

Wave Sensor	Wh/day	Ah/day
NW	56.16	4.68
NW II	28.32	2.36

TABLE II. POWER BUDGET OF TRIAXYS NW II

Phase	Power (W)	Typical Duration (sec)
Sleep	-	-
Warm Up	0.48	50
Sampling	1.5	1200
Processing	2.34	35
Idle	0.48	180

B. *Compact Size*

The TRIAXYS NW uses a stainless steel enclosure measuring 35cm (L) x 35cm (W) x 20cm (H) with a total weight of 13kg. The sensor size fits nicely inside the TRIAXYS wave buoy, and, when offering the sensor to clients for use on other buoy systems, the smaller footprint is always desired.

The TRIAXYS NWII is a compact, robust, long life product, with 85% reduction in volume, 15cm (L) x 15cm (W) x 9cm (H) and an 88% reduction in weight, 1.5kg. The TRIAXYS NWII enclosure is a non-corrosive, UV stabilized, EMC shielded, intrinsically safe, FRP impregnated enclosure with IP66 (NEMA 4X) protection classification.

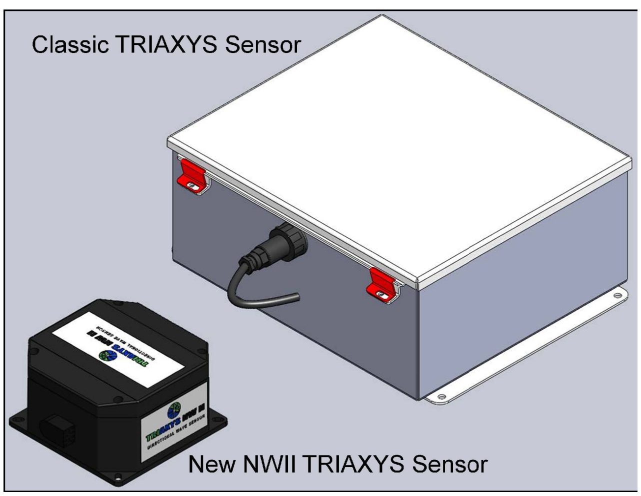

Fig. 4. *TRIAXYS NW vs. TRIAXYS NWII Enclosure*

C. *Specifications*

TABLE III. SPECIFICATIONS OF TRIAXYS NW II SENSOR

	TRIAXYS Directional Wave Sensor		
	Range	*Resolution*	*Accuracy*
Wave Height/Heave	±20m	0.01m	Better than 1%
Period	1.5–33 secs	0.1 sec	Better than 1%
Direction	0-360°	1°	3°
Sensor Size	15cm x 15cm x 9cm		
Sensor Weight	1.5 Kg		
Power Supply	10 to 20 VDC		
Input/Output	Power and data through single connector		
Communications	9,600 or 19,200 baud, 8 bits, 1 stop bit, no parity		
Operating Temperature Range	-30°C to +65°C		
Storage Temperature Range	-40°C to +70°C		
Sampling Frequency	Variable; default 4 Hz		
Frequency Range	0.64 Hz (1.5 seconds) to 0.030 Hz (33 seconds)		
Frequency Spacing	Variable; default 0.005 Hz		
Sample Duration	Variable (1 to 34 minutes)		
Sampling Interval	Variable (5 to 1440 minutes)		
Frequency Bands	Variable; default 123		
Location of Sensor	Any		
Data Storage	Internal 8GB: >5 years (expandable to 32GB)		

IV. TRIAL DATA

The TRIAXYS NWII is tested using a wave calibrator which enforces a controlled environment with known wave heights and periods. The TRIAXYS NWII has also been deployed in various sea trials, where both the TRIAXYS NW with the TRIAXYS NWII are mounted within the same buoy.

A. *Swing Calibrator*

The following table shows the TRIAXYS NWII results with a 2.0m wave tested with variable wave periods. Each test condition is tested for duration of 20min.

TABLE IV. TRIAXYS NWII – 2.00M WAVE CALIBRATION RESULTS

Period (s)	5.00	10.00	15.08	20.00	25.00	35.00
No. Waves	214	106	71	53	42	29
Hav (m)	1.99	2.00	2.00	2.00	2.00	2.01
Tav (s)	5.01	10.02	15.08	20.04	25.06	35.18
Hmax (m)	2.01	2.07	2.05	2.06	2.23	2.23
H13 (m)	2.00	2.03	2.03	2.03	2.09	2.17
T_H13 (s)	5.01	10.10	15.11	20.06	25.36	35.90
Hm0 (m)	2.82	2.84	2.82	2.83	2.83	2.87
Tp (s)	5.00	10.05	14.88	19.96	24.84	34.18

- Hav: Average zero down-crossing wave height. (m)
- Tav: Average zero down-crossing wave period. (s)
- Hmax: Maximum zero down-crossing wave height. (m)

- H13: Zero down-crossing significant wave height (m)
- T_H13: Zero down-crossing significant wave period (s)
- Hm0: Significant wave height, estimated from spectral moment m0. (m)
- Tp: Peak wave period (s)

B. Sea Trials

The following test data was collected from a sea trial where a buoy containing both the TRIAXYS NW and the TRIAXYS NWII was deployed on the La Perouse Bank in open Pacific Ocean. Located 48◦ 50.3167N, 126◦ 00.7154W, approximately 20 NM off the coast of Vancouver Island in 75m of water depth. This buoy was within 750m of Environment Canada Station 46206 & SCRIPPS Wave Station 195.

1) Testing

Data comparison between the TRIAXYS NWII and the SCRIPPS Wave Station 195 has been completed using the the coastal data information program, CDIP, analysis and comparative tool.

The TRIAXYS NWII and the SCRIPPS Wave station 195, were deployed in 1 m diameter hull, transmitting data every 30 min, implementing a compliant mooring.

2) Comparison

The following table summarizes the comparison between the TRIAXYS NWII and the SCRIPPS Wave station 195 average values, deployed from March 10, 2013 to April 10, 2013. Minimum recorded wave height of 0.5m and a maximum wave height of 11.9m.

TABLE V. TRIAXYS NWII VS. STATION 195 SUMMARY

Wave Parameter	**SCRIPPS Wave Buoy Average**	**TRIAXYS NWII Average**	**Average Difference**	**Average % Difference**
Hs (m)	1.99	1.95	0.04	0.02
Tp (s)	11.3	11.06	0.23	0.021
Ta (s)	7.48	7.78	0.3	0.04
Dp (deg)	258	259	1	<1%

The following graphs illustrate the comparison between the TRIAXYS NWII and station 195 regarding, significant wave height, peak period, peak wave direction and average period. La Perouse SCRIPPS 0 refers to Station 195, while La Perouse SCRIPPS 1 refers to the TRIAXYS NWII.

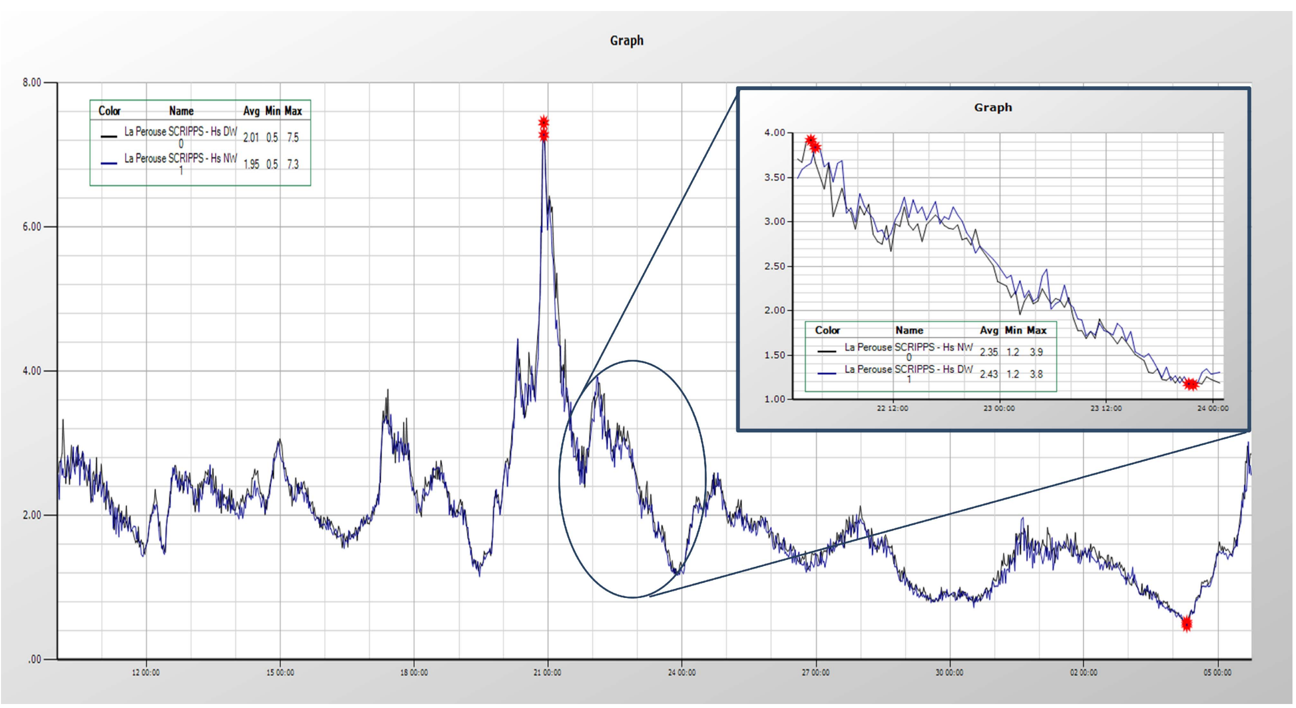

Fig. 5. *TRIAXYS NWII vs. Station 195 – Significant Wave Height (m)*

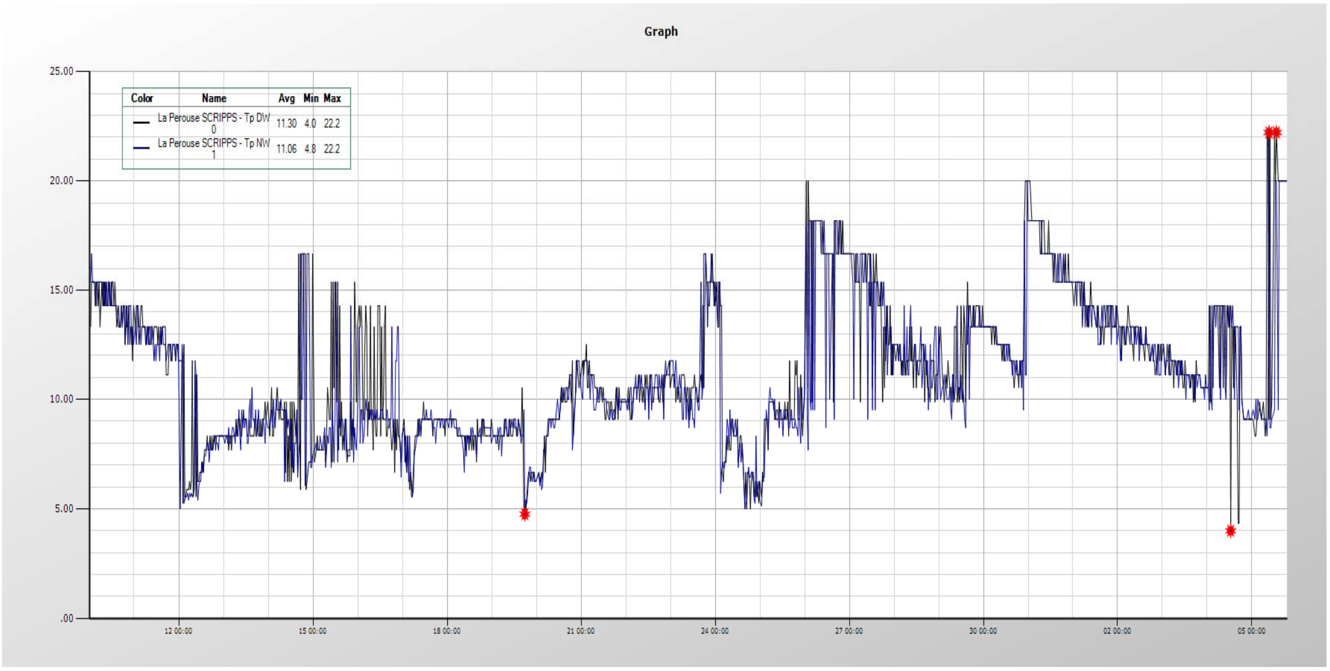

Fig. 6. *TRIAXYS NWII vs. Station 195 – Peak Period (s)*

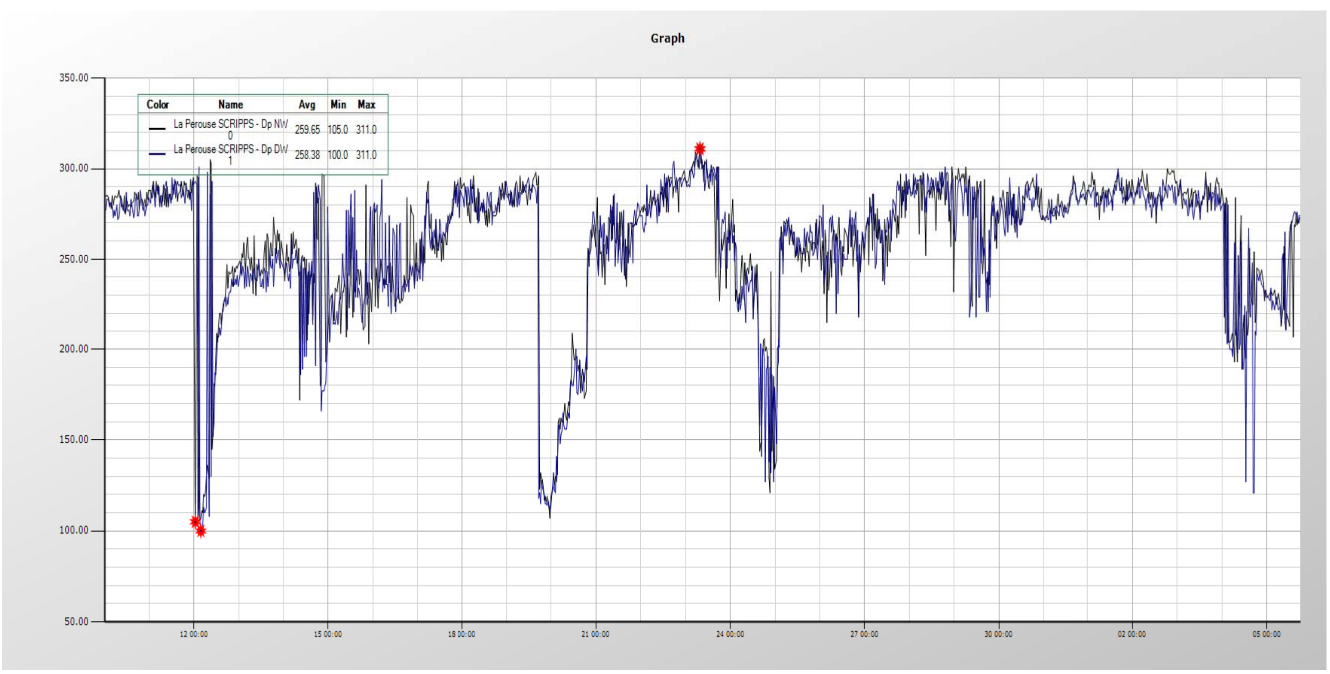

Fig. 7. *TRIAXYS NWII vs. Station 195 – Peak Wave Direction (deg)*

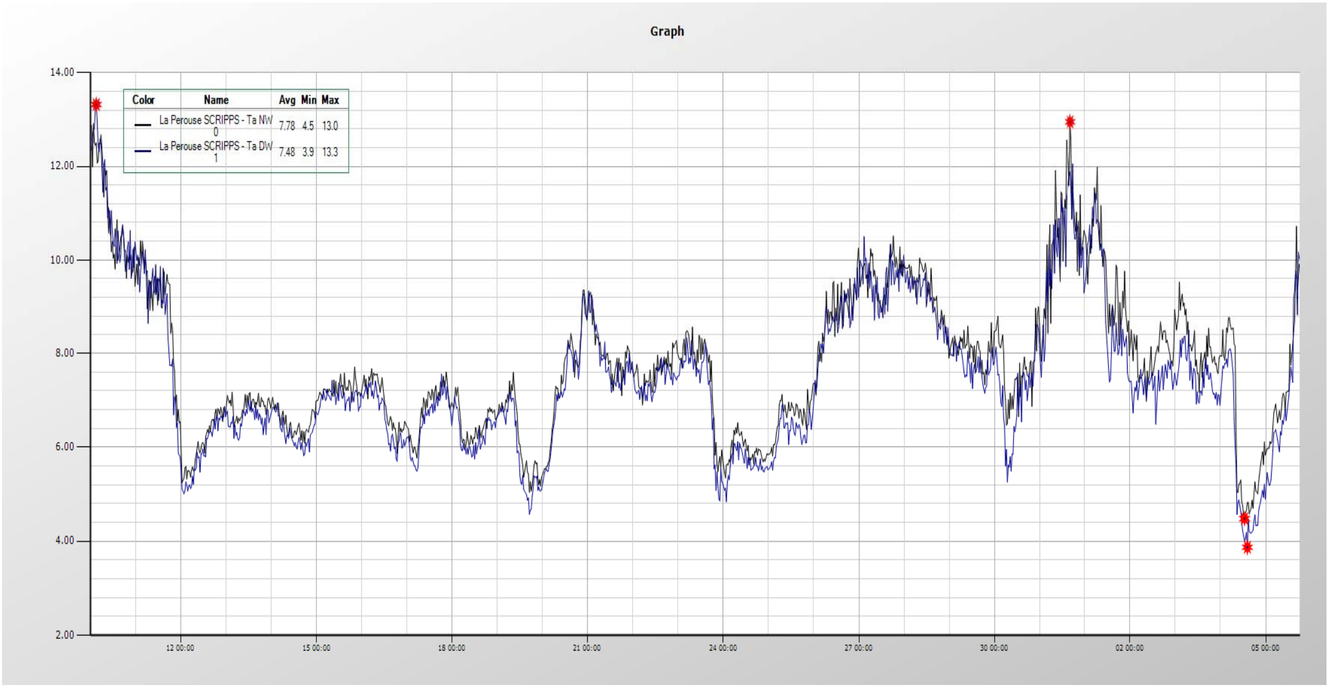

Fig. 8. *TRIAXYS NWII vs. Station 195 – Average Period (s)*

V. CONCLUSION

The successful development of the TRIAXYS Next Wave II incorporates a new inertial sensor for the measurement of motion equally as reliable and accurate as the previous TRIAXYS Next Wave and TRIAXYS Classic sensors. The NWII sensor has successfully met the objectives of reducing the power requirements of the sensor, as well as the footprint of the sensor. It is now a more adaptable sensor to be used on a variety of moored and drifter buoys, as well as other platforms requiring the measurement of directional waves.

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