ADVANCES IN BUOY TECHNOLOGY FOR WIND/WAVE DATA COLLECTION AND ANALYSIS

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ABSTRACT
Considerable advances have been made recently to reduce the cost of gathering meteorological and oceanographic data from coastal waters, especially for meteorological and oceanographic parameters such as wind speed and wave height. These advances have not compromised the technical quality of the data and have opened up the ability for coastal engineers and marine scientists to rely more on measured data for model input and development of engineering design criteria. With the innovative products being developed by Axys Environmental Systems (AXYS) collecting essential marine-related data is now easy and economically feasible.

INTRODUCTION

On the night of October 11, 1984 a rapidly deepening low-pressure system (known to local meteorologists as a 'bomb') moved out of the North Pacific and struck Vancouver Island. Seven vessels sank and five seamen drowned. The Canadian Atmospheric Environment Service (AES) was unable to detect the severe storm early enough to provide adequate warning to the fishing fleet. An inquiry was immediately launched to investigate the adequacy of marine weather forecasting on the West Coast of Canada. This lead to the establishment of a network of permanently moored buoys in the coastal zone and in the deep offshore on the West coast which was later expanded to include the East Coast of Canada and the Great Lakes. Today Canada has a network of over 40 operational buoy stations. Some of these are seasonal (Great Lakes, Lake Winnipeg and Great Slave Lake) and the rest are permanent (East and West coasts). This is the second largest network in the world to the US. The National Data Buoy Centre (Stennis Space Centre, Mississippi) maintains a network of about 60 buoys and 60 Coastal Marine Automated Network (C-MAN) stations. There are also other buoy networks in existence throughout the world.

ODAS

The data from this network of buoys, known as Ocean Data Acquisition Systems (ODAS), is transmitted hourly via geostationary satellite (GOES) and ends up on the Global Telecommunication System (GTS) of the World Meteorological Office (WMO) after various quality control checks have been performed.

Throughout the world there are buoy programs designed for both operational and climatological purposes. The Data Buoy Co-operation Panel (DBCP), established jointly by the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, enhances co-operation, co-ordination and information exchange among the operators and users of both drifting and moored buoys. The purpose of which is to improve both the quality and quantity of buoy data available on the GTS in support of the programmes of both the WMO and the IOC. Details of DBCP can be found from their website at http://dbcp.nos.noaa.gov/ .

This presentation does not address the developments in drifting buoys, but concentrates on moored buoys and the development of two new buoys in particular. For more information on drifting buoys and other moored buoy programs the reader is recommended to visit the DBCP web site.

Data Transmissions and Storage

Data gathered on buoys can be stored, transmitted or both. Data transmission can be via a number of ways.

Table 1 provides some of the presently available operational transmission options.

Table 1.

Transmission Mode	Orbit	Operational Cost	TX/RX	Comments
GOES/METEOSAT/ GMS etc.	Geo-stationary	Generally zero if data become public domain in real time.	TX only	Global coverage.
Inmarsat C.	Geo-stationary	Typically about 30c for 32 bytes of data	TX and RX	Global. Expensive if regular hourly data transmissions are required.
ARGOS	Low Earth Orbit	32 byte message only. Intergovernmental tariff rates. For private sector, of the order of $10/day. Double this if location is also required. Additional costs for use of 4 satellites to improve reception frequency in lower latitudes.	TX only	Global. Data reception in the tropics is vastly improved if the 4 satellites option is taken. Data transmissions from buoy are every 90 to 110 seconds. May only get 12 to 14 passes per day depending on location.
ORBCOMM	Low Earth Orbit	Similar cost to Inmarsat C	TX and RX	28 satellites in orbit.
VHF	N/A	Effectively zero. Unlimited amount of data	TX and RX	Local. Range limited to approximately 10 miles line of sight
Cell Phone	N/A	Varies but can be expensive	TX and RX	Continental. Cell coverage is getting better but coastal areas away from population centres may not be served.
Satellite phones (e.g. IRIDIUM)	Polar orbit	Varies but can be expensive	TX and RX	Global. Not yet fully operational.

Access to Real Time ODAS Data

Real time data from the ODAS buoys can be accessed through the Internet. One of the easiest to use for data from moored buoys is from the US National Weather Service. The address is http://www.nws.fsu.edu/buoy/B.

When accessing this site you will see the main screen which indicates the geographical areas from which buoy data is available. You will note that there are no data from the southern hemisphere. Clicking on one of the marine areas will bring the detailed map of the buoys in that area. By clicking again on a particular buoy the latest weather from that buoy can be seen. The data from the buoys include the current meteorological data of air temperature, sea level pressure and pressure tendency as well as the current wind and sea state data of wind speed, direction and gust, wave height and period and sea surface temperature. The data for the previous 24 hours is also given in tabular format.

Although the data from the ODAS network are potentially useful for coastal engineers and marine scientists, the network suffers from a number of disadvantages for specific users. Some of which are:

- the sites are located for marine forecasting purposes rather than for any particular engineering or scientific requirement. They may be too far offshore for any practical coastal engineering use;

- the parameters measured are typically suited for marine weather forecasting only;
- data from the southern hemisphere are not as easy to find;
- the buoys are expensive to purchase and require large ships for deployment and recovery operations.

To address these problems AXYS has introduced recently to the market two new buoys that may have a significant value for the coastal engineer and marine scientist. These are the TRIAXYS™ Directional Wave Buoy and the WatchKeeper™ Buoy. These buoys are relatively light, considerably less expensive than the ODAS buoys, and low on maintenance costs. Thus they are ideally suited for marine monitoring in support of coastal engineering and marine science. Specifications for these buoys can be seen at http://www.axystechnologies.com

TRIAXYS™ Directional Wave Buoy

The TRIAXYS™ Directional Wave Buoy is a precision instrument incorporating new technologies that make it an easy to use, rugged and economical buoy for accurate measurement of wave height, period and direction. The TRIAXYS™ sensor unit is comprised of three accelerometers, three rate gyros, a flux-gate compass, and the proprietary TRIAXYS™ Processor. The TRIAXYS™ Processor was developed from the successful low-power Watchman 100™ payload processor especially designed by Axys Environmental Systems for the marine environment.

A Joint Development by Axys and the National Research Council of Canada

The TRIAXYS™ buoy is the result of a collaborative development and testing program between Axys and the Canadian Hydraulics Centre (CHC) of the National Research Council of Canada. The directional wave analysis software in the TRIAXYS™ buoy is adapted from CHC software.

The CHC developed the buoy's software to analyse data from the six motion sensors and the flux-gate compass. The system processing software uses an iterative algorithm based on fast Fourier transform (FFT) analysis to solve the full non-linear equations of motion of the buoy in six degrees of freedom as defined by the measured accelerometer and angular rate gyro signals. Roll, pitch, and yaw angles, as well as displacements, velocities and accelerations for heave, surge, and sway can be computed at any reference point on the buoy. Since the full non-linear equations of motion are used, accurate motion data are obtained for extreme conditions with roll and pitch angles up to 60 degrees. As a result the directional wave characteristics are computed with much greater accuracy. The use of surge and sway velocities (instead of roll and pitch angles used in some other buoys) also provides a much better measure of the wave kinematics that define directional wave properties. Furthermore, full directional wave spectra can also be computed by the CHC maximum entropy method (MEM) in addition to the mean wave direction and the spreading width as functions of frequency. The software also performs a zero-crossing analysis to compute various time-domain wave parameters. Most of the data analysis is performed in the buoy with final presentation and data logging performed on a remote PC base station.

Through a process of simple menus the user can adjust many of the buoys' functions including the sampling duration and interval, storage options, transmission intervals and options, and test transmissions.

Other Innovative Features

Other innovative features of the TRIAXYS™ buoy are:

- full frequency domain and time domain wave analyses are done 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 transmission options (VHF, ARGOS, cell phone etc.)
- the buoy is solar powered thus avoiding the need for frequent battery replacement. The solar panels are housed inside a polycarbonate dome;
- the light, and transmission antenna are also housed inside the dome, leaving a completely clean exterior for ease and safety of deployment and recovery; and
- communication with the buoy is through an infrared port also housed inside the dome.

Results of Wave Measurement tests for TRIAXYS™ Directional Wave Buoy

a) Computer Simulation

Computer simulations were carried out at the CHC to evaluate the performance of the TRIAXYS™ directional wave buoy. The simulation results provide information on how accurately the buoy motions can be measured and how accurately the directional wave properties can be determined from the measured buoy motions. Simulations were performed for a variety of wave conditions with significant wave heights ranging from 1 to 16 metres and peak wave periods ranging from 5 to 20 seconds. Directional spectra with both narrow and broad spreading widths were simulated for a variety of mean wave directions.

b) Procedure

The simulations were performed using the CHC GEDAP software package. Standard GEDAP programs were used to synthesize random directional wave fields by the single summation method (Miles et al 1989) for specified wave spectra $S(f)$ and directional spreading functions $D(f, \theta)$. The wave synthesis procedure produced time series records of wave elevation, x and y velocity components and x and y wave slopes.

A custom GEDAP program was used to compute the actual buoy motions that would be produced by the synthesized directional waves. This program uses linear transfer functions for each of the buoy motions. For example, the heave response is modelled as a second order mass-spring system with a natural frequency of 0.42 Hz and a damping ratio of 0.6. Since the buoy is small compared to the wave lengths, it follows the orbital velocities of the waves over most of its operational frequency range. Thus, the heave motion is very similar to the wave elevation and the surge and sway velocities are the same as the north and west wave velocities resolved along the instantaneous x and y axes of the buoy as defined by the current yaw angle. Similarly, the roll and pitch angles of the buoy generally follow the local wave slope as resolved along the instantaneous x and y axes of the buoy. The yaw angle is modelled as a slow linear drift with a superimposed random oscillatory component.

The custom GEDAP program produces time series records defining displacement, velocity and acceleration for each of the actual buoy motions (roll, pitch, yaw, surge, sway and heave). Another program, MOTSYN4,

TRIAXYS™ Directional Wave Buoy

is then used to compute the sensor signals that would result from these motions. For example, each accelerometer would measure the total acceleration due to the translational and rotational motions of the buoy plus an earth gravity component depending on the instantaneous roll and pitch angles. Similarly, each angular rate sensor produces a signal proportional to the instantaneous rotation vector of the buoy resolved along the sensitive axis of the sensor.

Program MOTSYN4 also adds Gaussian white noise to each of the sensor signals to simulate the noise levels of the actual sensors. The RMS noise levels were set to 0.05 deg/s for the angular rate sensors and 0.0005 g for the accelerometers. These are the expected noise levels for the sensors when sampled through the 14 bit A/D converter. These noise levels were set at twice the RMS noise levels of 0.025 deg/s and 0.00025g that were obtained from the specifications and bench tests of the actual sensors using a 16-bit laboratory data acquisition system. The higher noise levels were used in the simulations to provide an allowance for additional sources of noise in the buoy, such as the signal conditioning and power supply components.

These synthesized sensor signals were then used as input to the wave analysis programs that are used in the TRIAXYS™ buoy for motion measurement and directional wave analysis. The output wave data were also processed by a program that is used in the

WaveView software (the buoy base station PC software), for directional wave analysis by the NRC Maximum Entropy Method.

The resulting data from the wave analysis programs that are used in the TRIAXYS™ buoy were then compared to the actual known characteristics of the directional waves that were used in the simulations.

c) Simulated Wave Conditions

Simulations were carried out for the eight test cases listed in Table 2. All waves were synthesized for a JONSWAP parent spectrum with $\gamma = 3.3$. The D5 test cases had a narrow directional spreading of $\cos^{2s}(\theta)$ with s=40 corresponding to a spreading width of σ_θ= 12.7 deg. The D6 test cases had a broad directional spreading of $\cos^{2s}(\theta)$ with s=6 corresponding to a spreading width of σ_θ= 31.7deg. The time series record length of the simulated sensor signals was set to 25 minutes for all of these test cases. The low frequency cut-off in program in the buoy was set to 0.030 Hz for all causes.

d) Actual Wave Conditions

Following the successful development of the buoy and the encouraging results from the computer simulated conditions, the TRIAXYS™ buoy was deployed within 100m of a directional Datawell buoy off the West coast of Vancouver Island, Canada in 33m of water. The results from a limited time of comparisons clearly indicate that the data gathered from the TRIAXYS™ buoy are very similar to that gathered from the Datawell.

Table 2.

Test Case	Spreading Width (degrees)	Actual Tp (s)	Actual Hmo (m)	TRIAXYS Tp (s)	TRIAXYS Hmo (m)
D5R1	12.7	4.96	1.01	4.95	1.01
D5R2	12.7	10.17	4.08	9.99	4.14
D5R3	12.7	15.23	8.94	15.00	8.95
D5R4	12.7	19.91	15.79	19.82	16.03
D6R1	31.7	5.89	1.23	5.94	1.22
D6R2	31.7	9.45	3.03	9.41	3.07
D6R3	31.7	13.82	7.44	13.84	7.46
D6R4	31.7	17.90	9.82	17.73	10.01

More than Just Waves

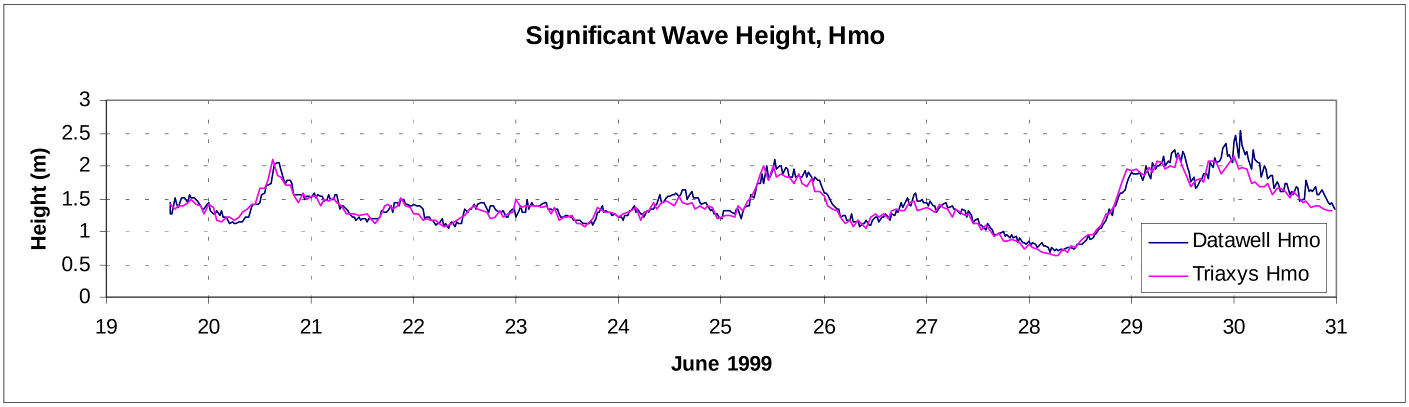
Many applications call for more than just wave data. From an engineering point of view wind speed and direction as well as current speed and direction may also be important. Also for those involved with water quality problems, the ability to monitor in real time such parameters as conductivity, fluorescence, radiation, DO and maybe colour, are useful. The WatchKeeper™ buoy can perform all these functions at a fraction of the cost of conventional buoys. It is the ideal dual function, low cost, low maintenance data collection and navigation buoy for coastal zone monitoring. The main limitation of this buoy is the power availability. For hourly data transmissions it is ideal for use during spring summer and fall seasons. If the buoy is to be used year round, then consideration must be given to reducing the data collection and transmission to every two or three hours unless battery replacement every four to six months is an option.

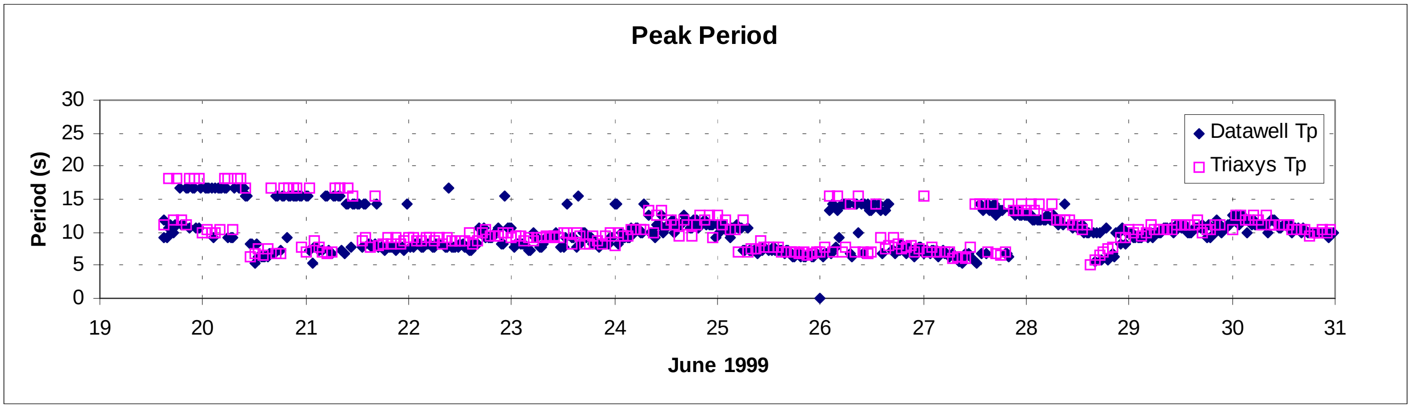
WATCHKEEPER™ BUOY

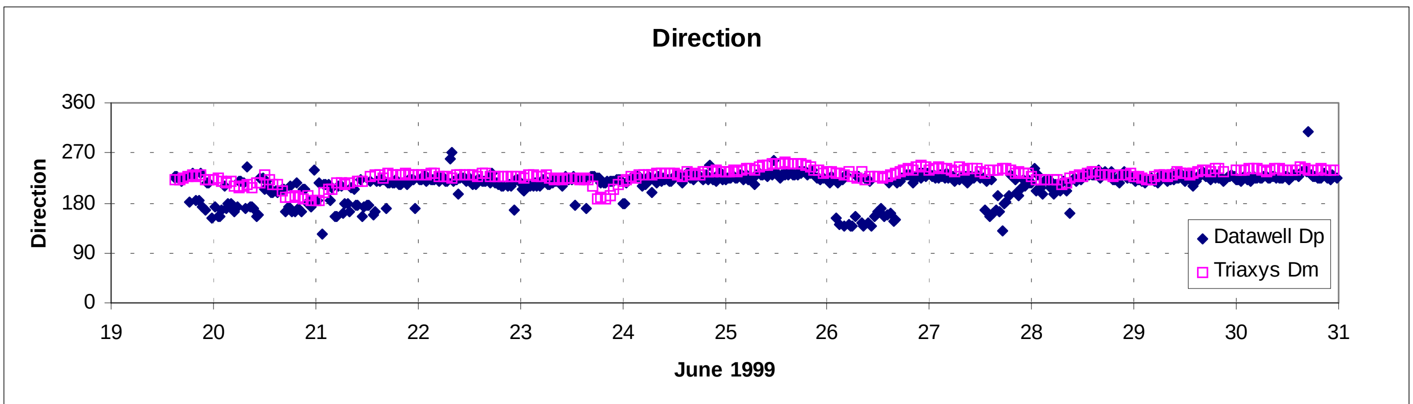
The WatchKeeper™ hull is an SB-138P Sentinel® buoy designed and built by Tideland Signal Corporation Medium density UV stabilised polyethylene is rotationally moulded to form a seamless, 9.5 mm thick hull filled with polystyrene foam. Colour pigment is blended into the polyethylene material eliminating the need for painting. These buoys are in use worldwide as navigation aids.

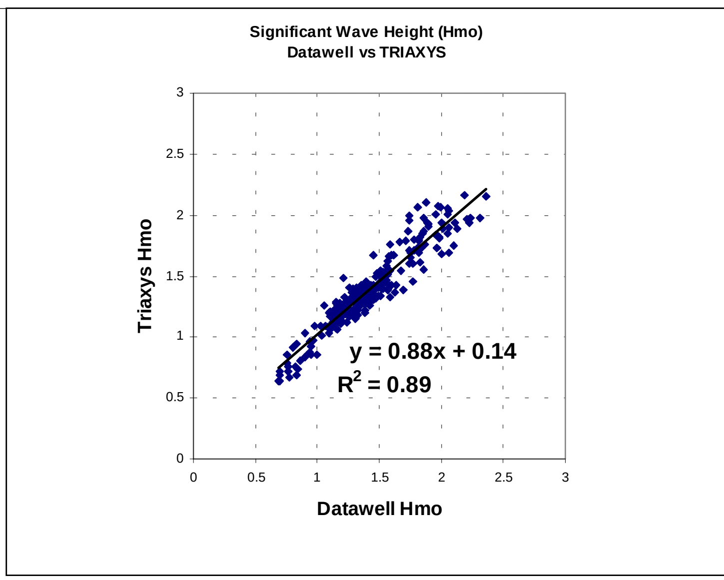
Axys Environmental Systems has adapted their successful Watchman™ payload to the Tideland hull to create a rugged, lightweight (540 kg) environmental monitoring buoy that maintains all the features and requirements for navigation aids (colour, top marks and day marks). It can be outfitted with a wide range of sensors for monitoring weather, air and water quality, waves and other parameters in coastal areas, lakes and rivers. Environment Canada has adopted the WatchKeeper™ buoy as their standard lightweight environmental monitoring buoy.

TRIAXYS Directional Wave Buoy and Datawell Directional Waverider Comparisons – June, 1999

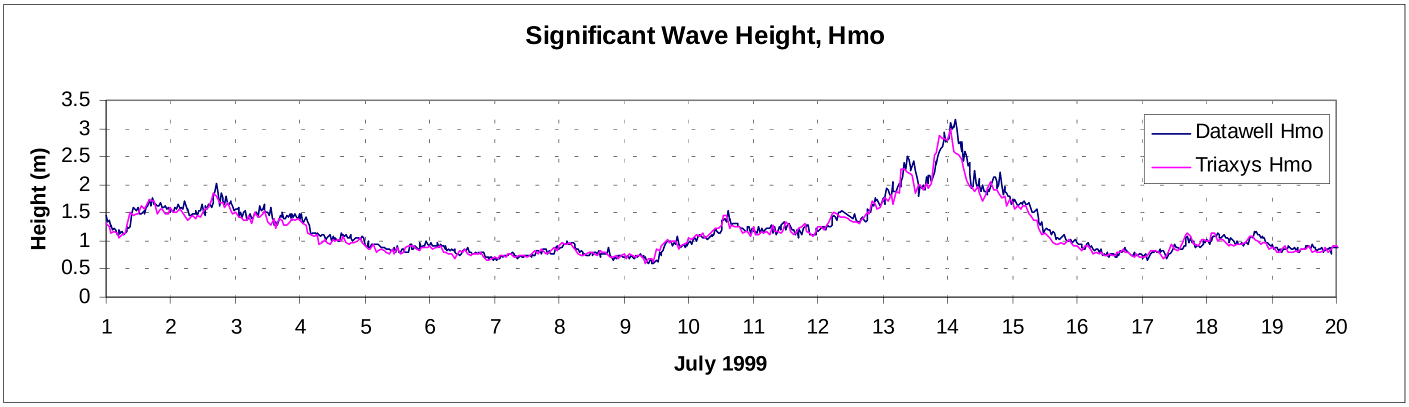


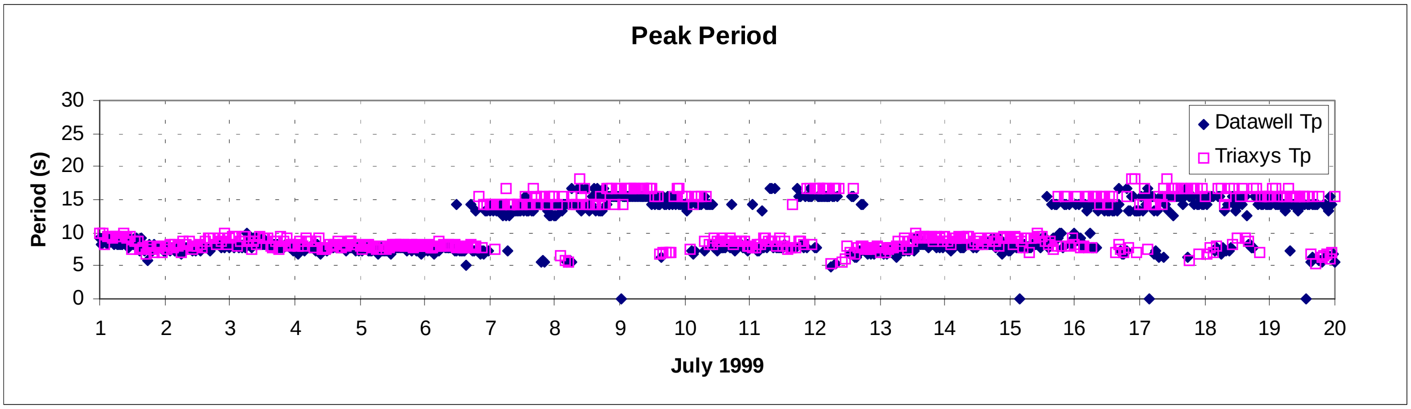


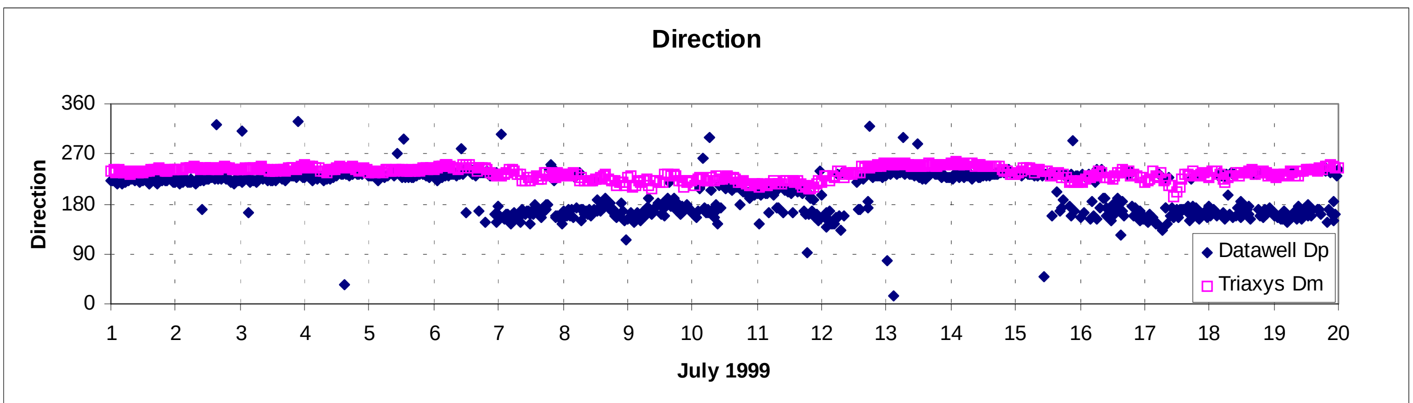


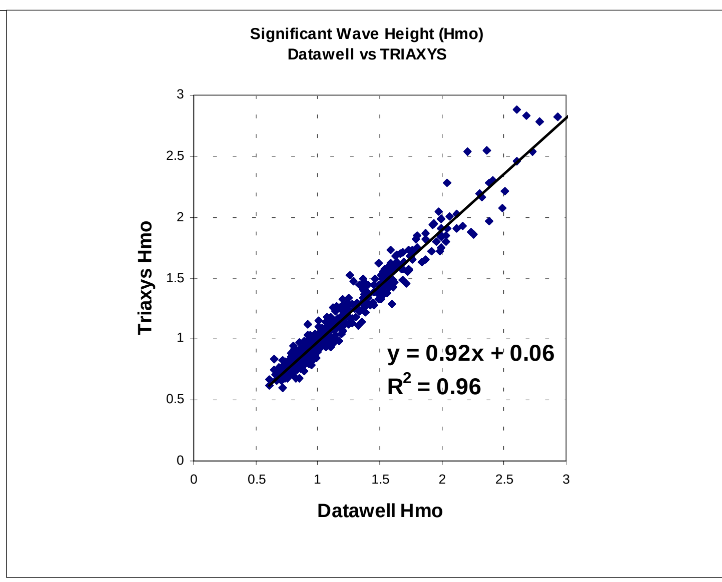


TRIAXYS Directional Wave Buoy and Datawell Directional Waverider Comparisons – July, 1999









SUMMARY

With these new buoys available for the measurement of winds, waves, currents and water quality parameters, it is now economically feasible for coastal engineers and marine scientists to measure marine parameters. Installations can be for a number of months (generally winter) or even years depending on the use of the data. The longer the record the more reliable the results of the statistical analysis.

Axys WatchKeeper Buoy

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