# Field tests of the new Datawell DWR-G GPS wave buoy

*GPS-based directional Waverider achieves 1 cm precision up to 100 s periods anywhere on the ocean*

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In the field of ocean wave measurement the (Directional) Waverider buoy (D)WR from Datawell has set the standard with over 4000 buoys sold. For over 4 decades governmental departments for coastal protection, marine constructors, the oil industry, harbour authorities, and oceanographic institutes have relied on these buoys for their wave data.

In the latest version, the DWR-MkIII featuring 3 years of continuous operation, the successful stabilised platform is still maintained. With this horizontal platform, one high-precision accelerometer suffices to obtain the wave height. In this way the principal wave parameter remains unaffected by other sensor errors.

Now Datawell introduces a totally different wave sensor concept: ***measuring waves using a single Global Positioning System (GPS) receiver***. Although GPS positioning at sea is common practice in navigation and even buoy monitoring, GPS wave measurement is still rare. So far only *differential*-GPS (DGPS), requiring an additional GPS reference station on shore, is available for wave measurement. However, because of its first-order atmospheric corrections, DGPS wave buoys are restricted to near-shore applications (circa 10 km). Furthermore, DGPS requires large amounts of data transfer leaving only short range communication means as a practical solution and reducing the buoy operational life. In contrast, the present *single*-GPS wave buoy features 1.5 years of continuous wave measurement and even operates on the open ocean.

While experiments on land demonstrate 1 cm precision up to 100 s periods, this investigation measures the performance of the new DWR-G buoy at sea. In a unique experiment the DWR-G is tested directly against the standard of its predecessor by merging the new GPS-sensor together with the conventional DWR accelerometer- and magnetic compass-sensors in a single buoy. Also, the occurrence of infra-gravity waves on the Australian east-coast nicely illustrates the performance in the long period wave regime.

## Existing wave measurement principles

Essentially wave sensors fall into two different categories: buoys following the wave orbital motion, and fixed-position sea surface elevation sensors. Pressure gauges and acoustic sounders on the seabed or microwave radars mounted on oil platforms are examples of the latter. The former category exploits linear and angular accelerometers or pitch-roll-meters combined with magnetic field sensors, and more recently DGPS.

On the one hand, surface elevation sensors (and state-of-the-art DGPS) can measure all long period waves, whereas low frequency accelerations ultimately become undetectable. On the other hand the new single-GPS and accelerometer wave buoys allow easy and flexible deployment for all depths and anywhere on the ocean without expensive structures or cables on the seabed.

In practice, existing accelerometer (and DGPS) wave buoys typically specify a 30 s wave period upper limit.

## Single-GPS measurement principle

Without going into the details, the GPS measurement principle bears a strong analogy with the Doppler-shift phenomenon of a nearby passing car blowing its horn. By monitoring the Doppler-shifted horn-frequency the speed of the car can be determined. Integration yields the motion of the car. In a similar way the DWR-G tracks the three-dimensional buoy motion.

The main specifications of the new Datawell GPS buoy are: 1 cm accuracy in three dimensions up to periods of 100 s. The latter limit is set by atmospheric disturbances. Furthermore, there is no longer the need for buoy calibration.

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## Field experiment

A standard Datawell 0.9 m diameter accelerometer-based DWR buoy was modified to accept the GPS-based DWR-G sensor. Housing the two sensor sets in one hull means they are both subject to the same wave motion. Also, time and even sampling (2 Hz) are synchronized for optimum comparison. This unique buoy was deployed for a period well over one month alongside the long-term monitoring buoy at the Gold Coast near Brisbane, Australia. The latter buoy is part of the Environmental Protection Agency (EPA) coastal monitoring network of Datawell Waverider buoys (see www.epa.qld.gov.au/waves). Its time is synchronized with respect to the test buoy but its sample rate of 2.56 Hz differs.

During the test two storm events with persisting swell occurred as witnessed in the significant wave height plot that follows. The seabed displays a uniform slope stretching out over several kilometres. Both buoys were moored in 17 meters of water some 100 m apart.

## Wave parameter correlation

To analyse amounts of data this large, correlation plots of various wave parameters are most suitable, see Figure 1. A single correlation plot allows comparison of the results from both wave sensors or both buoys over a whole range of marine conditions and over the full period of measurement. Every 10 minutes 1,024 GPS or accelerometer samples were used to compute all following wave parameters in the time domain and, after a fast Fourier transform, in the frequency domain. For a fair comparison the DWR-G wave measurements are high-pass filtered to eliminate the low frequency wave signals not measured by the conventional DWR.

As an example Figure 1(a) shows the correlation of the GPS and accelerometer-based significant wave heights $H_\sigma$, calculated as four times the standard deviation of the heave. Table 1 (left column) lists the *inter-sensor* correlation coefficients for all wave parameters. The maximum wave height $H_{mu}$ equals the maximum peak-to-trough heave difference between two zero-up-crossings of the mean sea level. $T_{zu}$ is the average zero-up-crossing period. In the frequency domain $S_p$ signifies the peak spectral density and $T_p$ the peak period. Finally, for these directional wave buoys, the peak wave direction $\alpha_p$ is the direction from which the predominating waves arrive and is measured clockwise from the north.

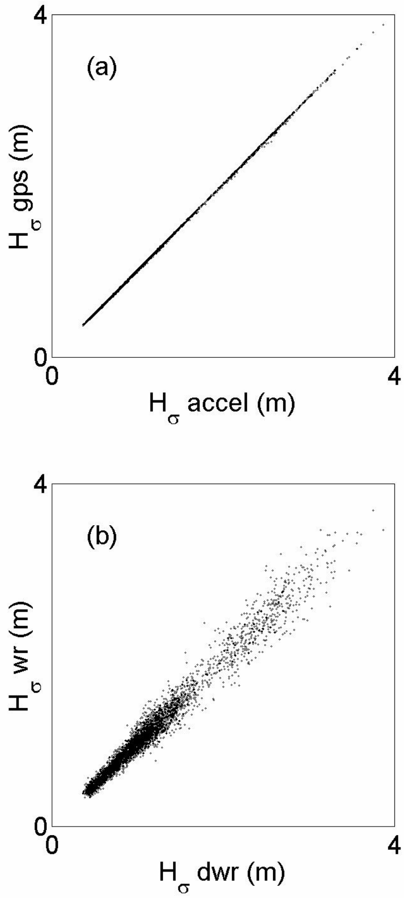


Figure 1. Correlation plots of the significant wave height. (a) Inter-sensor correlation, GPS versus accelerometer (accel) sensors integrated in a single buoy. (b) Inter-buoy correlation, DWR buoy (same as previous accelerometer sensor) versus WR buoy 100 m apart.

To put things in perspective we also correlated the non-directional WR and the DWR results. Again Figure 1(b) serves as an example. In Table 1 (right column) all *inter-buoy* correlation coefficients are given, except for $\alpha_p$ obviously.

As mentioned long period swell waves co-exist together with short period sea waves generated by the local wind. Occasionally swell and sea spectral peaks attain comparable magnitudes. The delicate balance variably decides in favour of the long or short period independent for both sensors or buoys leading to considerable scatter in the $T_p$ plots and explaining the weaker correlation. To preclude carry-over to the $S_p$ and $\alpha_p$ correlations only

Table 1. Overview of correlation coefficients.

| Wave parameter (units) | Correlation coefficients | |
|---|---|---|
| | inter-sensor (GPS-accel.) | inter-buoy (WR-DWR) |
| $H_\sigma$ (m) | 0.99994 | 0.9850 |
| $H_{mu}$ (m) | 0.9995 | 0.9431 |
| $T_{zu}$ (s) | 0.9937 | 0.8867 |
| $T_p$ (s) | 0.9787 | 0.6836 |
| $S_p$ ($m^2$/Hz) | 0.99995 | 0.8690 |
| $\alpha_p$ (deg) | 0.9977 | — |

pairs of data with the same $T_p$ within 10% are accepted.

Clearly, the extremely high inter-sensor correlation coefficients confirm that the GPS sensor almost exactly reproduces the accelerometer buoy wave measurement. Moreover, although one can not run with the hare and hunt with the hounds, we tend to conclude that such a good agreement between two wave sensors of totally different nature also reconfirms the high-quality of the conventional accelerometer-based DWR.

At the heart of oceanography lies the fact that wave parameters are representative of a certain area. In this respect the inter-buoy correlations are illustrative, showing the effect of a 100 m buoy displacement even if the WR and DWR differ slightly. Across all parameters, the inter-buoy correlations prove weaker than the inter-sensor correlations. From these results it is evident that a mere 100 m shift in position may be more critical than switching between accelerometer and GPS wave sensor.

## Long period waves

Apart from a pure oceanographic interest there is also an economic motivation to understanding and predicting the long period waves. While acting on berthed ships these infra-gravity waves may not only delay loading and unloading but can even cause severe damage. In general, and to prevent such incidents in particular, EPA is highly interested in new wave sensors for application in their network.

In the present field test 40 cm low frequency waves were observed. These offer a good opportunity to study the low frequency wave performance of the DWR-G. However, for reference we now have to turn to theoretical predictions.

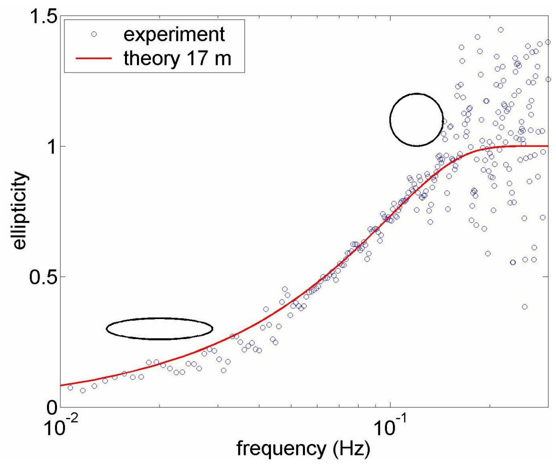



Figure 2. Wave ellipticity against frequency as measured on June 30 and as calculated for the local water depth of 17 m.

Through directional Fourier analysis, the wave ellipticity as a function of frequency is obtained, Figure 2. The ellipticity measures the ratio of the vertical wave amplitude to the horizontal. For depths much larger than the wavelength the water particles in the waves move in circular orbits, ellipticity ≈ 1. In shallow water particle paths are much more flattened with ellipticity < 1, see the shapes in Figure 2. Given the local depth the theoretical ellipticity as a function of the wavelength or wave frequency may be computed.

At the high frequency side both the horizontal and vertical wave amplitudes are small (cm's) and the ellipticity becomes noisy. Away from this the agreement with theory is good. This not only supports the low frequency sensitivity of the GPS sensor, but also indicates that the mooring is still appropriate. Also of some note, the local depth could in fact be determined from the ellipticity.

To study long period waves over time the low frequency significant wave height $H_{\sigma,low}$ is introduced. Its definition is identical to that of $H_\sigma$, except that the heave signal is low-pass filtered beforehand. The filter cuts off frequencies above 0.033 Hz (periods below 30 s). Similarly $H_{\sigma,high}$ the high frequency significant wave height is obtained after high-pass filtering with the same cut-off. Figure 3 shows the time-variation of both after smoothing by a 10-sample running average. A roughly proportional relation is found.

The low frequency waves probably are 'surf beat' as first reported by Munk and are generated by short waves in the surf zone on a

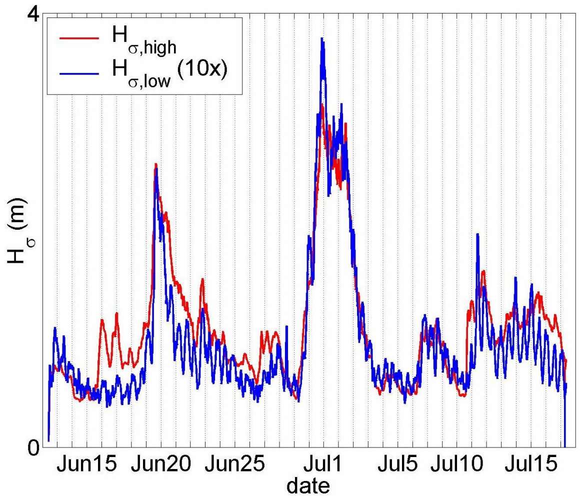


Figure 3. Smoothed low (magnified 10 times) and high frequency significant wave height.

sloping coast. Indeed, the linear relation between the long and short period wave heights has been established before [Tucker]. The small modulation of the $H_{\sigma,low}$ signal precisely coincided with tidal peaks but will not be discussed within this context.

Recently, EPA purchased a DWR-G to further investigate surf beat in relation with surf-zone morphology and longshore currents.

## GPS signal loss

The DWR-G relies on the signals of GPS satellites. If these signals are masked in such a way that insufficient GPS satellites are visible, the measurements will be interrupted. It remains to be seen to what extent data will be lost under various marine conditions. However, the present experiment showed very little data loss—one incident of a few seconds loss per day on average even up to significant wave heights of 4 m.

## Selective Availability

Furthermore, for strategic reasons the GPS system has been fitted with the possibility of Selective Availability (SA). Should SA be switched on, this will render the DWR-G non-usable for the time that SA remains active.

## Conclusions

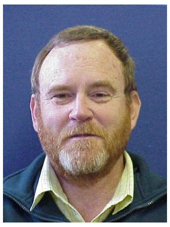
The Datawell DWR-G directional wave buoy presents a new valuable instrument to the ocean wave measuring community. This work has shown that it offers the same high-quality data as the well-established accelerometer-based DWR's, albeit with 1.5 years of continuous operation compared to 3 years of the DWR-MkIII. Because the DWR-G relies on the GPS system, no calibration is required. In particular, the DWR-G may be put to good use if long period waves up to 100 s waves are of interest, e.g. open ocean swell waves, resonances in harbours or channels, and perhaps even seismic activity. No DGPS reference station is required, so there is no near-shore restriction. Finally, easy-to-handle compact DWR-G versions (able to follow shorter waves) are feasible and will soon be introduced.

## References


Munk, W.H., "Surf beats", *Transaction American Geophysical Union*, Vol. 30, No. 6, pp. 849-854, 1949.

Tucker, M.J., "Surf beats: sea waves of 1 to 5 min. period", *Proc. Roy. Soc.*, London, Ser. A., 202, pp. 565-573, 1950.





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