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COMPARISON OF CONTEMPORANEOUS WAVE MEASUREMENTS WITH A SAAB WAVERADAR REX AND A DATAWELL DIRECTIONAL WAVERIDER BUOY

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1. INTRODUCTION

This paper presents the results of our investigation into the difference discovered between simultaneous wave measurements conducted with a Datawell Directional Waverider MkIII Buoy (DWR) and a non-directional SAAB WaverRadar REX (SAAB) located about 3 km apart in 125 m water depth on the North West Shelf (NWS) of Western Australia.

The SAAB was mounted on Woodside Energy Limited's North Rankin A (NRA) platform located on the NWS of Australia about 135 km north-northwest of Dampier (Figure 1). NRA was the first gas and condensate production facility on the NWS, commissioned in 1984 and wave measurements using Datawell Waverider buoys (non-directional 1983 to 1991 and directional 1992 to 2011) have been conducted adjacent to/near the platform since 1983. The SAAB WaveRadar is used primarily as an air gap sensor and only became operational in October 2006. The SAAB is a downward-looking microwave radar, which was mounted underneath and several metres from the end of the north oriented ~183 m long flare-bridge on the platform, sitting about 26 m above the water surface. The DWR is a 0.9 m diameter heave, pitch and roll buoy with an internal raw data logger and Argos top hatch, and it was moored about 3 km to the southwest of the platform (i.e. in order to avoid contact with work vessels) in water depth of 125 m on the shelf slope, with the local bathymetric contours oriented roughly NE/SW. Apart from a fairly shallow bank (i.e. that comes to within ~30 m of the surface), located about 60 km WSW of the platform the local shelf/slope bathymetry offshore is relatively featureless (Figure 1).

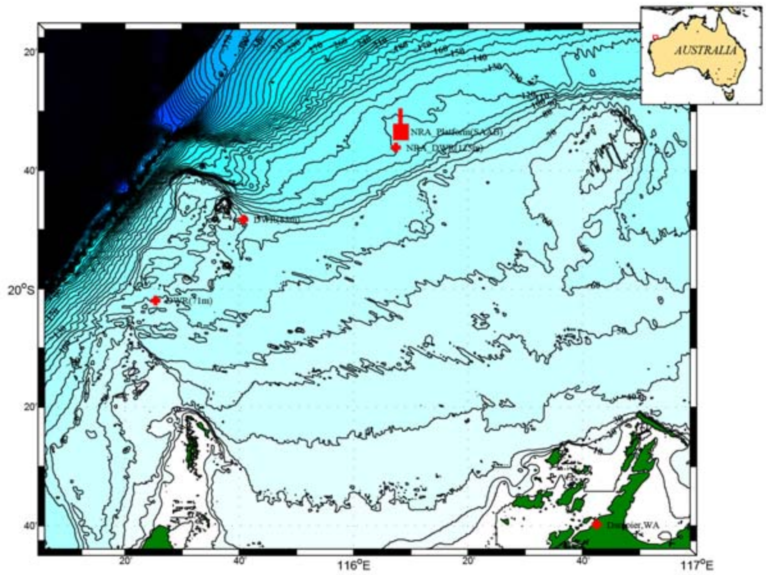

Figure 1 Location diagram illustrating the local bathymetry and the DWR and SAAB measurement locations offshore Dampier, Western Australia.

The predominant ambient swell direction in the area is from the WSW (~75%) throughout the year. While ambient seas alternate, approaching mostly from the WSW (~45%) and SW (~30%) in the summer months of September to March and from the WSW (~25%), ENE (~20%) and E (~15%) in the winter months of April to August. Tropical cyclones also affect the area in the months of December to April, approaching predominantly from the N – E (~90%) and only occasionally from the NW (~10%). Thus, the majority of tropical cyclone generated waves (~50%) will approach the platform from a roughly NE direction.

As part of another study conducted for the region, the waves measured from the NRA DWR in 125 m were being compared against waves measured from another DWR located in 83 m water depth about 52 km to the WSW (Figure 1). Unfortunately, there were some missing data from the NRA DWR in 125 m during the period of interest, so it was decided to use the non-directional NRA SAAB wave data to fill in the gap.

As the SAAB wave data had never previously been used for any analysis, a brief comparison was conducted between the SAAB and the DWR (125 m water depth) using about 2.5 months of limited, readily available, overlapping data, which covered the end of summer and the beginning of winter (March to May 2010). The comparison, which used 30 minute record internal logged DWR data and 20 minute SAAB data, showed that the waves (total significant height) measured by the SAAB were about 5% lower than those measured by the slightly more exposed DWR, located only about 3 km away. This result was somewhat surprising, because from previous work done in the region, we had found that the difference in total significant wave height from the NRA DWR in 125 m to the DWR in 83 m separated by 52 km was only about 6%, and a similar earlier comparison between the NRA DWR in 125 m and another DWR which was deployed about 88 km to the SW in 71 m water depth, was also within about 6% (Figure 1).

It was thus decided, that additional research was warranted (i.e. this paper) to try and determine why such a significant difference (~5%) existed between the SAAB and DWR wave measurements, both in 125 m water depth and only about 3 km apart. This investigation/ additional research included accessing additional overlapping data measured by the SAAB and DWR, re-processing both data sets from the raw profiles to get more similar data sampling schemes for comparison. We then conducted spectral or frequency domain analysis on the data sets, along with correlation and ambient statistical analysis to address operational and storm total, sea and swell waves (height and period), wave directionality (from the DWR) and any other factors that may cause differences in the data (i.e. platform sheltering from certain directions, instrument specifications and/or performance).

2. AVAILABLE DATA

Overlapping DWR and SAAB measured wave data were available over the 4.8 year period from late October 2006 to late July 2011. However, there were some significant gaps in the two data sets and as a result we restricted the bulk of our analysis to the most continuous two year period, 1 May 2008 to 30 April 2010, when the most complete set of raw wave profiles were available for both instruments. This two year period also displayed some inter-annual variation in wave conditions, as it included one quite severe winter period, one more benign winter period, one quite severe summer period and one more benign summer period. The summer periods also included four rather weak tropical cyclones (i.e. with $H_{s\ tot}$ ranging from only 3 to 4 m). For wave comparison under more severe tropical cyclone storm conditions, additional data were available and used for analysis from 12 storm events (i.e. with $H_{s\ tot}$ ranging from 3.5 to 8.0 m) selected from the total 4.8 year measurement period of 2006 to 2011. Each storm event consisted of 3 to 6 days of measured wave data, covering the wave build up to the storm peak and the wave decrease after the storm peak.

The DWR and SAAB were both supplied calibrated by the manufacturers; however, we also undertook additional in-house calibration of the DWR heave sensor prior to deployment (i.e. the

DWR was rotated in an in-house 2 m diameter wheel at periods of 5, 10, 15, 20 and 25 seconds). This ensured that it was operating within the manufacturer's specifications (Note: upon final recovery, the DWR will also be similarly calibrated). For general comparison, the manufacturer's quoted accuracy for the DWR and SAAB are detailed as follows:

	Range	Accuracy	Resolution
DWR Heave	-20 to +20 m	±0.5 to 1%	0.01 m
DWR Direction	0° to 360°	±0.4° to 2.0°	1.5°
SAAB (ASL)	3 to 65 m	±0.006 m	0.012 m

Note: the SAAB had a beam width of 10°, and was mounted 26 m above the sea surface, which resulted in coverage at the surface of 4.55 m (diameter) and also meant that the shortest wave period resolvable would be 2.4 seconds (i.e. quite similar to the DWR).

3. DATA SAMPLING SCHEMES

The individual logged raw profiles from both the DWR and the SAAB were visually inspected using RPS in-house wave data visualisation and editing software. Any anomalous profiles were flagged as 'bad' and excluded from subsequent analysis. Any obviously erroneous data points were replaced with 'nulls', and the records were then retained for subsequent analyses.

The data sampling schemes for the DWR and SAAB adopted for final analysis in this study are detailed in the following table:

Sampling Schemes	**DWR**	**SAAB**
Record Interval	60 minutes	60 minutes
Samples	2048	4096
Sample Interval and Frequency	0.78125 sec and 1.28 Hz	0.5 sec and 2.0 Hz
Total Record Time	26 mins 40 sec	34 mins 08 sec
Ensembles	15	15
Ensemble Size	256	512
Ensemble Overlap	128	256
Frequency Bins	128	256
Frequency Bin Width	0.005 Hz	0.00390625 Hz
Frequency Range	0.005 to 0.640 Hz	0.00390625 to 1.0 Hz

The above sampling schemes were specifically chosen so that the data from the DWR and SAAB would be as similar as possible for comparison purposes, especially the frequency bin widths (i.e. the original frequency bin widths for the DWR and SAAB were 0.005 Hz and 0.0078125 Hz, respectively, etc).

4. DATA ANALYSIS

The following data analyses were conducted:

Frequency Domain or Spectral Analysis

The DWR and SAAB wave profiles (after QC) were analysed in the frequency domain. The energy spectrum was estimated from the time series records using a Fast Fourier transform technique. The following wave parameters were then derived from the wave spectra (i.e. directional spectra were only available from the DWR):

- significant wave height, H_s (metres);
- average zero crossing period T_z (seconds);
- mean wave period T_m (seconds);
- period of the peak spectral ordinate, T_p (seconds), where T_p = centre point of the frequency band containing maximum energy; and
- direction of the peak spectral ordinate, θ_p (degrees), for the frequency band containing maximum energy.

The above parameters were computed for the complete spectrum, and for the two portions of the split spectrum, derived using a separation frequency of 0.111 Hz (9.0 seconds), to provide the corresponding sea and swell component parameters. The separation frequency of 0.111 Hz was selected as the most appropriate value for identification of long period swell emanating from the Southern or South Indian Ocean.

Time history check plots of all of the available above parameters for total, sea and swell waves were produced for the DWR and SAAB to ensure that no spurious or erroneous data points had made it through the initial processing and profile QC stage, and that all the resultant wave data were usable for subsequent reliable analysis (i.e. correlation, ambient statistical, etc).

Correlation Analysis

There were many instances where correlations were required, to establish relationships between related parameters (i.e. DWR and SAAB wave heights and periods).

In all instances, dependent and independent parameters were identified, such that correlation could be achieved via linear regression analysis using vertical least squares (with the dependent parameter on the ordinate).

To make interpretation of the results easier, the ‘lines of best fit’ were constrained through the origin. The DWR data was placed on the x-axis for all correlations, because the instrument is considered the benchmark device (by the offshore industry) for measuring waves in deeper water, and the DWR was also able to be further calibrated in-house (i.e. in addition to the manufacturer’s calibration).

Correlation analyses were conducted for operational total, sea and swell wave conditions (using the continuous 2 years of overlapping data) and for separate tropical cyclone storm wave conditions (i.e. using the combined data from the 12 larger storm events from the 4.8 years of data). Using the wave directions from the DWR, the two data sets were also separated into easterly (0° to 179°) and westerly (180° to 359°) waves for correlation analysis.

Ambient Statistical Analysis

For general comparison purposes, ambient statistical analysis (i.e. to calculate minimum, maximum, mean, standard deviation and exceedence percentiles) was conducted on the DWR and SAAB wave heights and periods (total, sea and swell) derived from the frequency domain analyses.

5. RESULTS

In summary, the numerous correlations and statistics generated as part of this study showed the following:

Correlation Analysis Results for All Waves (2 years 2008 to 2010)

- Both the omni-directional and easterly (0° to 179°) total and sea wave heights (H_s) measured by the SAAB were about 4% and 6% lower (per the slopes), respectively, than those measured by the DWR (Note: the more similar data sampling scheme chosen for this study decreased both of the omni-directional values by 1%, from those found in a previous study);

- The westerly (180° to 359°) total and sea wave heights (H_s) measured by the SAAB were about 3% and 5% lower (per the slopes), respectively, than those measured by the slightly more exposed DWR;

- The omni-directional, easterly (0° to 179°) and westerly (180° to 359°) swell wave heights (H_s) measured by the SAAB were all virtually the same (with slopes within +/- 1%) as those measured by the DWR;

- The correlation coefficients for the omni-directional and easterly (0° to 179°) total, sea and swell wave heights (H_s) were all very good (i.e. > 0.95), while those for the westerly (180° to 359°) total, sea and swell waves (H_s) were not as good with values of 0.79, 0.78 and 0.85, respectively (i.e. the platform may be causing some slight shielding of the westerly waves measured by the SAAB);

- All of the wave periods (T_p and T_m) for omni-directional, easterly and westerly total, sea and swell waves measured by the SAAB were within +/- 3% of those measured by the DWR, except for the easterly (0° to 179°) total spectral peak wave period (T_p) which was ~16% higher for the SAAB with an extremely poor correlation coefficient of only 0.095 (Note: a visual review of time history overlay plots showed good agreement between the easterly DWR and SAAB total T_p values, which indicates that this poor correlation is most likely due to some instability in allocating the total T_p to either sea or swell waves);

- Correlation coefficients for T_m were significantly better than those for T_p, ranging from 0.89 to 0.95 for omni-directional and easterly total, sea and swell waves and from 0.57 to 0.81 for westerly total, sea and swell waves;

- Correlation coefficients for T_p typically ranged from 0.66 to 0.79 for omni-directional and easterly total, sea and swell waves (except for the easterly T_p total mentioned above with a correlation coefficient of only 0.095) and from only 0.39 to 0.59 for westerly total, sea and swell waves; and

- During slightly higher (H_s > 2.0 m) ambient total, sea and swell wave conditions, the wave heights (H_s) measured by the SAAB were all slightly more lower than those measured by the DWR (i.e. omni-directional and easterly waves were up to 6% less and westerly waves were up to 8% less).

The following table, Table 1, presents the correlation summary results for the omni-directional, easterly and westerly total, sea and swell waves (H_s, T_p and T_m) using all of the wave data from the DWR and SAAB for the 2 year period May 2008 to May 2010:

Correlation Analysis Summary Statistics for DWR (x-axis) versus measured SAAB (y-axis) Waves																	
Location and period of data	Wave Type	Corel Param.	Data for Correlations														
			All Data (Omni-directional)					Easterly Data					Westerly Data				
			No. of Points	Correl Coeff	Slope	Std	Intcp	No. of Points	Correl Coeff	Slope	Std	Intcp	No. of Points	Correl Coeff	Slope	Std	Intcp
North Rankin A Platform North Western Australia (May 08 - May 10)	Total	H_s	16214	0.967	0.962	0.880	0	2370	0.961	0.957	0.129	0	13843	0.793	0.971	0.182	0
		T_p	16214	0.756	1.002	1.742	0	2370	0.095	1.158	1.687	0	13843	0.552	0.982	2.315	0
		T_m	16214	0.947	1.037	0.314	0	2370	0.901	1.024	0.202	0	13843	0.766	1.038	0.691	0
	Swell	H_s	16214	0.948	1.001	0.071	0	2370	0.953	1.002	0.085	0	13843	0.852	0.999	0.114	0
		T_p	16214	0.733	0.992	1.150	0	2370	0.697	0.985	1.417	0	13843	0.586	0.994	1.380	0
		T_m	16214	0.914	0.989	0.302	0	2370	0.889	0.981	0.338	0	13843	0.810	0.991	0.447	0
	Sea	H_s	16214	0.975	0.942	0.079	0	2370	0.955	0.947	0.123	0	13843	0.781	0.953	0.188	0
		T_p	16214	0.664	1.026	0.869	0	2370	0.791	1.005	0.504	0	13843	0.391	1.029	1.212	0
		T_m	16214	0.916	1.020	0.180	0	2370	0.906	1.014	0.169	0	13843	0.569	1.024	0.391	0

Table 1 Correlation analysis summary statistics for the DWR versus SAAB for omni-directional, easterly and westerly total, sea and swell wave data for the 2 year period May 2008 to May 2010.

Correlation Analysis Results for 12 Tropical Cyclone Storms (4.8 years 2006 to 2011)

- For the 12 storms (with H_s ranging from 3.5 to 8.0 m), the omni-directional total and sea wave heights (H_s) for all of the storm data measured by the SAAB were about 5% and 9% lower, respectively, than those measured by the DWR (similar, but slightly worse/lower than the ambient result); and for storm waves greater than 4 m, the SAAB was even slightly more lower by about 6% and 10% (i.e. the under estimating increases slightly as the wave heights increase);
- For the 12 storms, the omni-directional swell wave heights (H_s) for all of the storm data measured by the SAAB were about 4% higher than those measured by the DWR (i.e. this differs from the ambient result, where they were about the same); and for storm waves greater than 4 m, the SAAB was only about 1% lower than the DWR;
- For the 12 storms, all wave periods for total, sea and swell waves measured by the SAAB and DWR were within +or- ~4% (similar to the ambient result); and
- For the 12 storms, the correlation coefficients were best/very good for the total, sea and swell wave heights (> 0.95), good for the spectral mean wave periods (0.71 to 0.94) and not so good for the spectral peak wave periods (0.52 to 0.74).

The following table, Table 2, presents the correlation summary results for the omni-directional, total, sea and swell waves (H_s, T_p and T_m) using the tropical cyclone storm wave data from the DWR and SAAB for the 12 events (H_s ranging from 3.5 to 8.0 m) over the 4.8 year period 2006 to 2011:

Correlation Analysis Summary Statistics for DWR (x-axis) versus measured SAAB (y-axis) Waves												
Location and period of data	Wave Type	Corel Param.	Data for Correlations									
			All Data					Where HsTotal of DWR >= 4m				
			No. of Points	Correl Coeff	Slope	Std	Intcp	No. of Points	Correl Coeff	Slope	Std	Intcp
North Rankin A Platform North Western Australia	Total	H_s	1552	0.965	0.952	0.191	0	116	0.831	0.936	0.291	0
		T_p	1365	0.596	1.007	1.256	0	112	0.693	0.997	0.584	0
		T_m	1376	0.936	1.036	0.268	0	112	0.844	1.016	0.225	0
	Swell	H_s	1552	0.957	1.035	0.169	0	116	0.842	0.991	0.327	0
		T_p	1365	0.519	0.961	1.119	0	112	0.688	0.973	0.486	0
		T_m	1376	0.713	0.958	0.487	0	112	0.755	0.966	0.247	0
	Sea	H_s	1552	0.952	0.908	0.161	0	116	0.879	0.896	0.221	0
		T_p	1366	0.739	1.000	0.638	0	112	0.189	0.999	0.325	0
		T_m	1376	0.878	1.014	0.238	0	112	0.47	1.001	0.233	0

Table 2 Correlation analysis summary statistics for the DWR versus SAAB for 12 tropical cyclone storm events, with $H_{s\ TOT}$ ranging from 3.5 to 8.0 m, from the 4.8 year period October 2006 to July 2011.

The above correlation analysis utilised from 3 to 6 days of hourly wave data measured/spanning the peak of each of the 12 storm events and showed that for omni-directional total wave heights (H_s), the SAAB was only about 5% lower than the DWR. However, if just the maximum total wave height (H_{stot}) values measured at the storm peak by the SAAB and DWR are compared, it shows that on average (over the 12 storms) the SAAB is under estimating by about 16% (i.e. ranges from 0% to 25% for the 12 storm events), which is quite significant, especially if the SAAB data were to be used for any extreme analysis purposes.

Ambient Statistical Analysis Results for All Waves (2 years 2008 to 2010)

- For omni-directional total and sea waves the SAAB maximum and the 20%, 5% and 1% exceedence percentile wave heights (H_s) are less than the DWR wave heights by 2 to 7% and the minimum and mean wave heights are the same (i.e. the higher the wave heights the more the SAAB tends to under-read);

- For the omni-directional swell waves the SAAB and DWR were virtually the same (i.e. correlation slopes within 1%), except for the maximum wave height (H_s), where the SAAB was less by about 10%;

- All of the statistics on wave periods (T_p, T_m and T_z) between the SAAB and DWR compare quite well (within +/- 4%), except for the total and swell wave maximum T_p values, which were within +/- 7 to 9%.

The following table, Table 3, presents annual statistical summary results for the omni-directional total, sea and swell waves (H_s, T_p, T_m and T_z) using all of the wave data from the DWR and SAAB for the 2 year period May 2008 to May 2010:

Annual Statistical Analysis Summary Statistics for DWR and SAAB																
Location and period of data	Wave Type	Parameter	DWR							SAAB						
			Min	Max	Mean	Std	Exceedence Percentile			Min	Max	Mean	Std	Exceedence Percentile		
							20	5	1					20	5	1
North Rankin A Platform North Western Australia (May 08 - May 10)	Total	H_s	0.4	5.3	1.4	0.5	1.8	2.4	3.1	0.4	5.1	1.4	0.5	1.7	2.3	2.9
		T_p	3.5	20.0	10.8	3.6	14.3	15.4	18.2	3.7	18.3	10.9	3.5	14.2	16.0	18.3
		T_m	3.9	12.8	6.5	1.3	7.4	9.2	11.0	4.0	13.3	6.8	1.4	7.8	9.6	11.2
		T_z	3.6	12.1	5.7	1.1	6.4	7.8	9.3	3.5	11.8	5.8	1.1	6.5	8.0	9.4
	Sea	H_s	0.3	3.8	1.1	0.5	1.5	2.1	2.8	0.3	3.7	1.1	0.5	1.4	2.1	2.6
		T_p	2.6	9.0	7.0	1.5	8.7	9.0	9.0	3.3	9.0	7.2	1.5	9.0	9.0	9.0
		T_m	3.1	7.1	4.9	0.6	5.5	6.0	6.4	3.3	7.1	5.0	0.6	5.6	6.0	6.4
		T_z	2.8	6.8	4.6	0.6	5.1	5.6	6.0	3.0	6.7	4.6	0.6	5.0	5.5	5.9
	Swell	H_s	0.3	4.1	0.8	0.3	1.0	1.4	1.8	0.2	3.7	0.8	0.3	1.0	1.4	1.8
		T_p	9.0	20.0	12.7	2.2	14.3	16.7	18.2	9.0	21.3	12.7	2.2	14.2	16.0	18.3
		T_m	9.6	16.7	12.3	1.0	13.1	14.0	15.1	9.6	16.6	12.1	1.0	13.0	13.9	14.9
		T_z	9.6	16.5	12.1	1.0	12.9	13.8	14.8	9.6	16.3	12.0	1.0	12.7	13.7	14.7

Table 3 Operational or ambient annual omni-directional summary statistics for the DWR and SAAB total, sea and swell wave data for the 2 year period May 2008 to May 2010.

6. CONCLUSIONS

We've undertaken a fairly comprehensive comparison (i.e. using correlation and ambient statistical analysis) of simultaneous measured waves from a DWR and SAAB, and come to the following conclusions:

- Compared to the DWR, the SAAB under-estimates total and sea wave heights during both ambient (2 years of data) and tropical cyclone (12 storm events) conditions, typically by 4 to 6 % and 5 to 10%, respectively;

- The under estimation of wave heights by the SAAB, increases as the wave heights increase (i.e. worse for larger storms with $H_s > 4$ m) and even more so at the peak of the storm (i.e. with an average under estimation of about 16% for the 12 storm events);

- Wave direction makes no significant difference to the comparison results, with correlation slopes essentially the same (within +/- 1%) for omni-directional, easterly and westerly waves, although there was a slight decrease in correlation coefficients for westerly waves (i.e. possibly due to some slight platform shielding);

- The SAAB and DWR measured essentially the same for swell wave heights (i.e. with correlation slopes within 1% for the perennial WSW swell) under both ambient and storm conditions; and

- For wave periods, the SAAB and DWR compared quite well with correlation slopes typically within +/- 3 to 4%.

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