Relative Performance of Directional Waverider buoy, Laser, and WaveRadar during a Tropical Cyclone off the North West Coast of Australia

Pramod K. Jangir[1] *, Kevin Ewans[1-2] *, Alexander V. Babanin[1] *

[1]The University of Melbourne, Australia; [2]MetOcean Research Ltd., New Zealand

Email: pjangir@student.unimelb.edu.au, kevin.ewans@unimelb.edu.au, a.babanin@unimelb.edu.au

Abstract

Accurate ocean wave measurements are needed for the safe design and operation of offshore facilities, but despite plenty of ocean wave measurements, wave analysis remains troubled by continuing uncertainty on what exactly the instruments are measuring and how accurate those measurements are. Of paramount importance are measurement during extreme sea states. We examine measurements made with a Datawell Directional Waverider buoy, an Optech Laser and a Rosemount WaveRadar at the North Rankin A during a TC. We evaluate the performance of these instruments at NRA, during TC Veronica (H_{Smax} = 7.5 m & U_{10max} = 29 m/s), which formed on 20 March 2019, including their performance from QC, and results from various statistical intercomparisons based on significant wave height and wave periods derived from wave spectrum. We also analyse the distribution of wave crest elevations and significant wave heights derived from the wave sensors along with their probabilities of exceedance from a specified limit. The results from QC and the comparisons permit us to conclude on the performance of the instruments and the most suspected cause of discrepancy in the measurements.

1 Introduction

In the first phase of this project, we examine the measurements made with the Opetch Laser, the Rosemount WaveRadar and the Datawell Directional Waverider Buoy (DWR) at the North Rankin A (NRA) during the tropical cyclone Veronica, which occurred on 20 March 2019. We evaluate their performance by performing various spectral and time domain analyses of the measured data. These instruments use different measurements principles and methods for the wave measurements. The Laser and the Radar provide the measurements of range to the sea surface. On the other hand, the DWR measures the surface acceleration in x, y, and z directions, which are double integrated to get the surface displacements. The Laser and the Radar measurements are Eulerian measurements based on range measurements from their respective platform locations to the sea surface, but they have significantly different footprints at the sea surface. The DWR has a rubber cord in it's mooring, allowing it follow the water movements, so effectively making Lagrangian measurements.

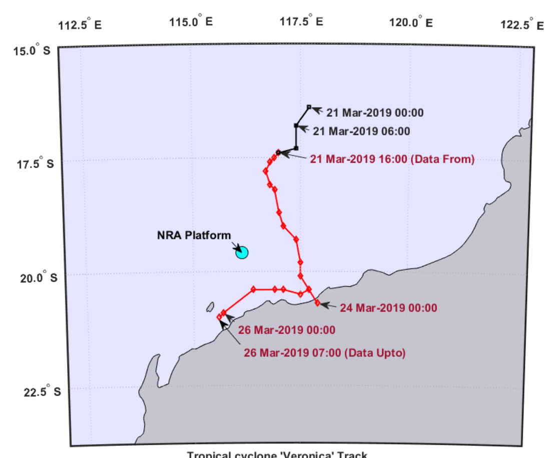

Figure 1: Location of the North Rankin A (NRA) platform and the track of tropical cyclone Veronica.

2 Data Intercomparisons

2.1 Quality Control Procedure

For accurate comparison of wave measurements of these instruments, the quality of the data should be good. In order to improve the data quality, we perform quality control procedure over the raw data and check for the quality flags values to determine whether the data pass or fail our QC check. If the data fails the QC-check, we remove those points where a significant flag exists and replace that value by performing linear interpolation. We also estimate the percentage of the interpolation performed (relative to the total record length) to ensure the interpolation does not have a significant effect on the actual wave measurements.

Tropical Cyclone "Veronica" , NRA, (21 March,2019 16: 00 - 26 March, 2019 06:30:00)			
Quality Flag	Max. No. of Occurrences		
	Laser	WaveRadar	DWR MkIII buoy
1. Number of two consecutive equal value	28	0	0
2. Largest number of consecutive equal values	3	0	0
3. Number of values > 5 x sigma	5	0	0
4. Number of value difference > 5 sigma	36	5	0
5. Minimum of values in the records	7.29	-5.27	-6.88
6. Maximum of values in the records	5.8243	5.38	7.29
7. Min. of coefficient of 1st order term in polyfit	-0.1355	-0.1114	-0.006
8. Min of constant term in polyfit	-0.015	-0.004	-0.0041
9. Mean of raw values	-0.015	-0.004	-0.0041
10. Mean of detrended values	0	0	0
11. Probability of getting flag 1 or larger	0.1994	1	1
12. Probability of getting flag 2 or larger	0.0094	1	1
13. Probability of getting flag 3 or larger	0	1	1
14. Probability of getting flag 4 or larger	0	0	1
15. Probability of getting flag 5 or smaller	0	0.99	0.04
16. Probability of getting flag 6 or larger	0.012	0.99	0.0024
17. Probability of being flag 7 equal to zero	0	0	0.87
18. Probability of being flag 8 equal to zero	0.0028	0.883	0.88
19. Probability of being flag 9 equal to zero	0.003	1	1
20. Probability of being flag 10 equal to zero	1	1	1

Table 1: Maximum number of occurrences of the flags in the wave samples of the Laser, Radar, and DWR.

2.2 1-d Frequency Spectra and Tail Slopes

At weak wind forcing (wind measurements taken at NRA using anemometers), when $\frac{U_{10}}{C_p} < 1$, and $H_s \approx 4.5$ m (Figure 2a), all three sensors have an energy peak centered near 0.09 Hz. Energy at the peak of Laser is approximately 36% and 51% less than Radar and DWR, respectively. Moreover, for a nearly fully developed sea ($\frac{U_{10}}{C_p} \approx 1$) (Figure 2b), at a sea state of $H_s \approx 5.2$ m, energy at the peak (0.09 Hz) of Laser is nearly 10% higher than Radar, but 20% less than DWR. As the wind forcing strengthens ($\frac{U_{10}}{C_p} \approx 1.78$), wind input to waves increases, waves are steeper, and there is more energy at the peak(≈ 0.10). At higher sea states, $H_s \approx 6.5\,m$ (Figure 2c), energy at the Laser peak is approximately 19% and 9% less than Radar and DWR, respectively. Further, at very low sea states, ($\frac{U_{10}}{C_p} \approx 1.78$ & $H_s \approx 1.3$ m, Figure 2d), energy at the Laser peak(0.17 Hz) is approximately 6% , and 1% higher than Radar and DWR energies at the peak, respectively. The f_t in the figure 2 is the transition frequency (f^{-4} to f^{-5}), which has been estimated according to [1]. In summary, the peak energy difference is larger at the higher sea states than at the lower sea states. DWR and Radar energies at the peak is higher than Laser through out the dataset, except for a few time series measured at the low sea states.

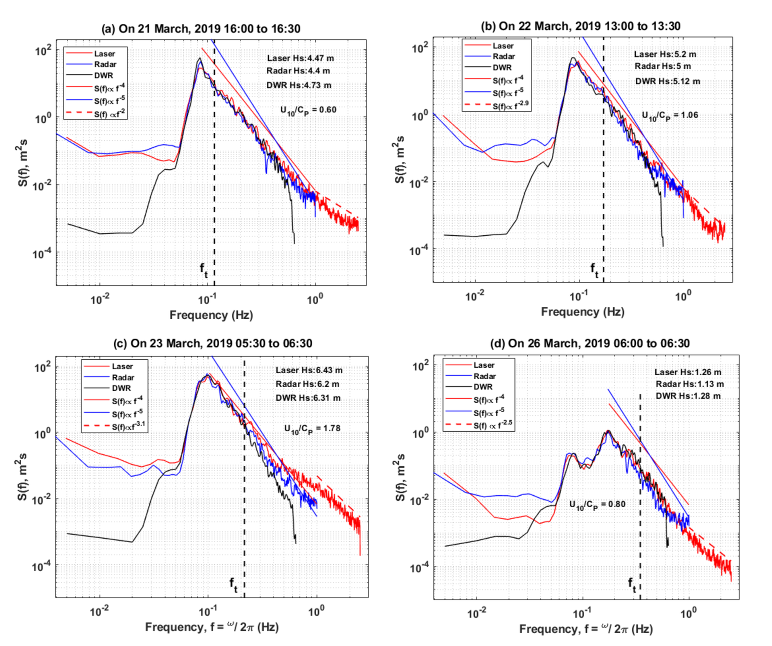

Figure 2: Power spectral density (m^2s), estimated from the Laser, Radar, and DWR data.

In the dataset of the Laser and the Radar, the transition from f^{-4} *to* f^{-5} over the wind speed range of 3.82 to 28 m/s, has been observed at a transition frequency, $f_t \approx 2f_p - 4f_p$, but for the DWR, the transition has been observed between both $2f_p - 4f_p$ and $4f_p - 6f_p$ frequency ranges.

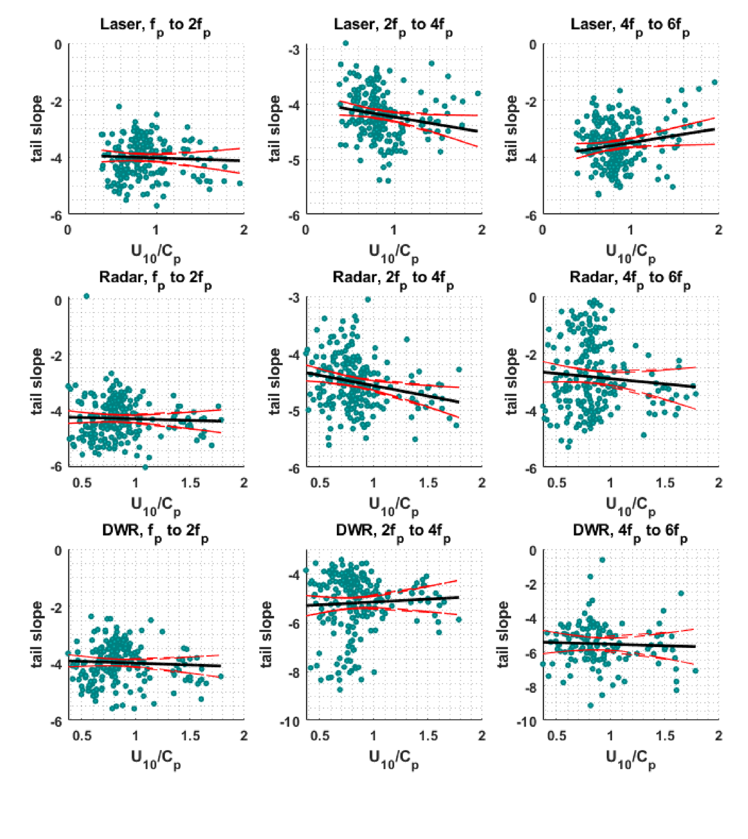

Figure 3: Scatter plots of high frequency tail of the Laser, the Radar, and the DWR spectra vs U_{10}/C_p.

2.3 Mean Spectral Ratio

Superimposition of spectra on the same plot is a simple way of comparing the two frequency spectra, which can also be used to find consistence biases between the instruments, and also to establish a spectral calibration. The spectral ratio, (r(f)) is estimated as $r(f) = \frac{S(f)_L}{S(f)_R}\frac{\nu_R - 2}{\nu_R}$, where ν_R is the degree of freedom of the Radar spectrum[3].

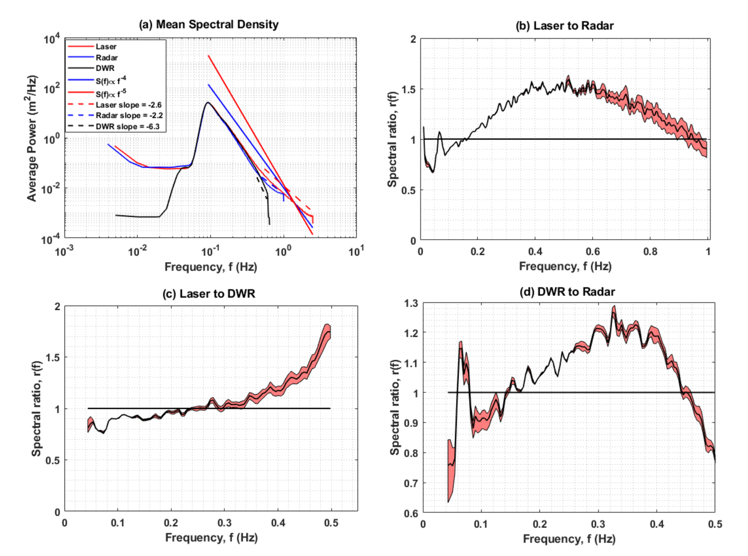

Figure 4:(a) Mean spectral density (m^2s); mean spectral ratio: (b) Laser to Radar; (c) Laser to DWR; and (d) DWR to Radar, with 95% confidence intervals(red color).

The differences in the spectral estimates of the Laser and the Radar are suspected to be caused, at least in part, by the non-linearity introduced by the discrepancies associated with the difference in the footprint diameter at the wave crest and wave trough measurements of these instruments.

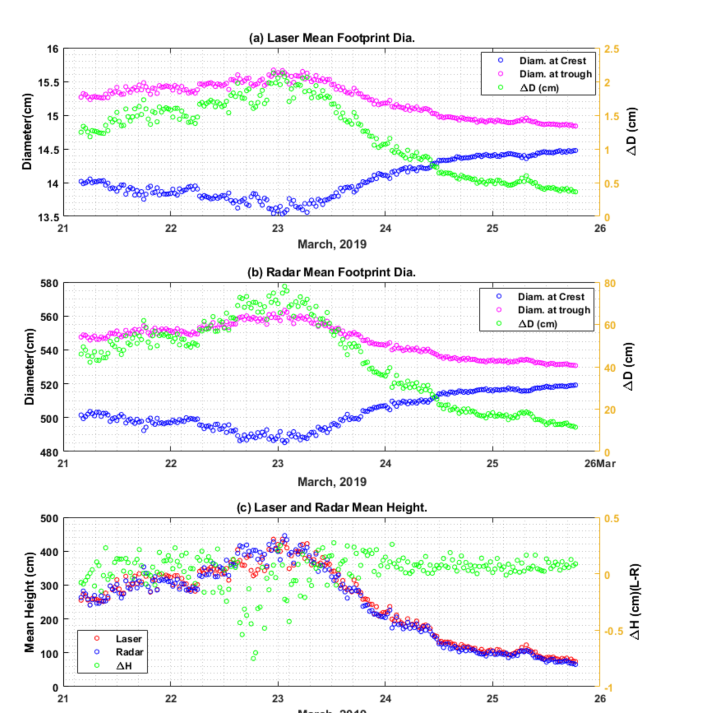

Figure 5:(a) Laser mean footprint diameter at wave crests and wave trough; (b) Radar mean footprint diameter at wave crests and wave trough; (c) Laser and DWR mean wave height.

2.4 Scatter Plots and Descriptive Statistics

For significant wave height, the mean error, RMSE, and standard deviations are not very informative; they give the impression of much better agreement than can be justified from the scatter plot. Nevertheless, the bias between Laser H_{m0} and DWR H_{m0} is less than the Laser H_{m0} and the Radar H_{m0}, while the bias between the DWR H_{m0} and the Radar H_{m0} is approximately same as the Laser and the DWR. However, the relative error is significantly different for all the three instruments. The relative error in H_{m0} measurement between the Laser and the DWR (0.001) is significantly less than that between the Laser and the Radar, and the DWR and the Radar (Figure 6). The increased bias shown in the Laser vs the Radar H_{m0} can be accounted for the change in the intercept of the line. The non-parametric regression shows evidence of a change in the nature of relationship in the higher sea states which is driving the change in the intercept and hence in the estimated bias. The bias in T_{m01}, T_{m02}, and crest wave period, T_C between the Laser and the DWR is higher than the Laser and the Radar because the T_{m01}, T_{m02}, and T_C of the Laser are significantly lower than the Radar and the DWR.

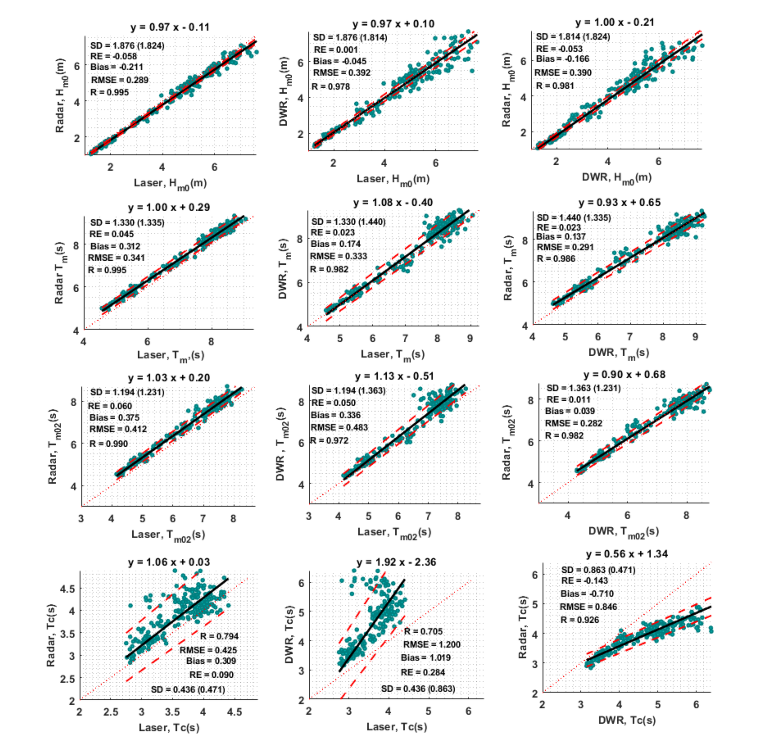

Figure 6: Passing Bablok non-parametric regression between the significant wave heights(H_{m0}), mean wave periods (T_{m01}), zero-crossing wave periods(T_{m02}), and crest wave periods (T_c) of the Laser, the Radar and the DWR.

3 Conclusions

On average, the Laser estimates are lower than the Radar for a frequency band of 0.01-0.06 Hz when these frequencies are below the peak frequency, but its estimates are higher than the Radar at all frequencies above the peak frequency. According to theoretical analysis[2], the Radar is expected to perform well in a frequency range of 0.06 to 0.6 Hz. However, the Radar spectral estimates at all the frequencies falling in this range, and even above 0.6 Hz are lower than the Laser until 0.94 Hz. In addition, the DWR spectral energy is higher than the Laser for a frequency band of 0.04-0.24 Hz, but above 0.24 Hz, the DWR spectral estimates are smaller than the Laser. The DWR is also higher than the Radar over the most of the frequency range.

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