Field Trials of the WaveRadar REX^2

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Introduction

The WaveRadar REX is a platform-based wave measurement system with close to one thousand installations across six continents. WaveRadar REX has supported offshore and coastal operations for over twenty years. RS Aqua have been working in conjunction with Emerson's Rosemount Tank Gauging division since 2017 to develop and trial the next generation of WaveRadar – the REX^2. The WaveRadar REX^2 is a variant of the Rosemount 5408 level gauge with significant hardware, firmware and software modifications that make it suitable for measuring ocean waves. Further modifications have also been made to ensure backwards compatibility with existing WaveRadar REX installations so WaveRadar REX^2 a drop-in replacement. This document describes two of the field trials of the WaveRadar REX^2.

Technical Benefits

The WaveRadar REX^2 is a new, innovative sensor with significant technological improvements over its predecessor. The WaveRadar REX^2 has an order of magnitude reduced power draw, with an average power consumption 0.4W (1W peak). This substantial reduction in power consumption makes "off-the-grid" deployments possible, with power supplied solely by renewable energy and batteries.

The new sensor is significantly reduced in size and weight (see Figure 1), weighing only 8.5 kg without the mounting flange. The WaveRadar REX^2 features a construction of stainless steel 316 and PTFE, providing excellent resistance to corrosion. The new sensor also features an LCD screen built into the head of the unit, displaying the real-time measurement distance and gives the user a quick indication of the sensor's status.

Figure 1 – Comparison image of the new WaveRadar REX^2 (right) and its predecessor, the WaveRadar REX (left).

The microwave frequency of the WaveRadar REX^2 is a frequency modulated continuous wave (FMCW) sweep around a 26 GHz midpoint. This frequency band is not subject to the export controls that 10 GHz sensor encounters.

The measurement technique used by the WaveRadar REX^2 is slightly different to the legacy sensor. In the legacy sensor, each measurement is made using one sample with alternating up or down FMCW sweeps. To correct for doppler shift, the sample is averaged with the most recent previous sample. Whilst this corrects for doppler shift, it does introduce a lag to the measurement. The WaveRadar REX^2's uses a burst data mode which makes two measurements together, using both an up and down sweep. These sample pairs are averaged to correct for the doppler shift and a

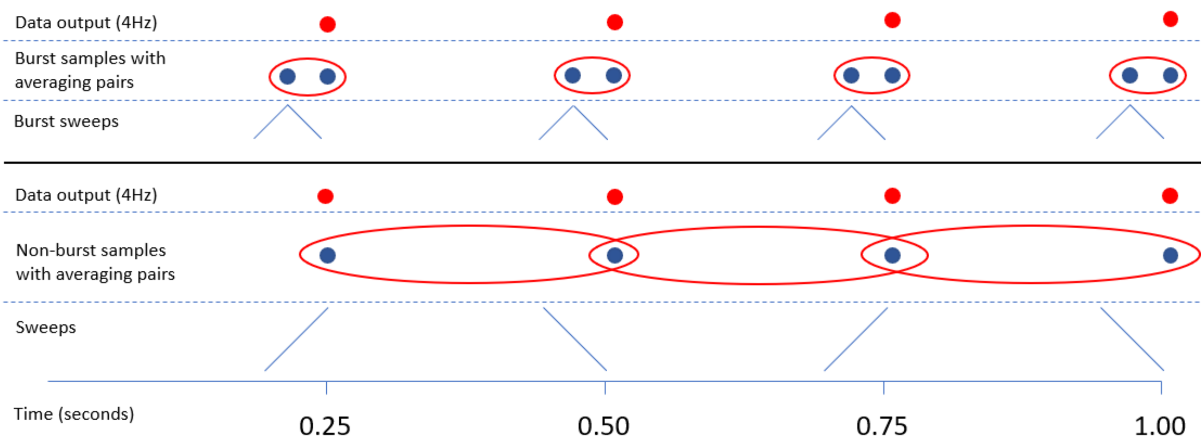


Figure 2 – Diagram showing the difference between the burst data sampling technique and the single (non-burst) measurement technique used by the WaveRadar REX².

single measurement is output. This is further explained by the diagram in Figure 2. Using this burst technique drastically reduces the time between averaged samples and removes the lag present in the legacy measurement method, synchronising the sea surface measurement with data output. When sampling faster than 5Hz, the WaveRadar REX² reverts to the non-burst sampling method.

A full comparison of technical specifications between the two sensor types can be found in Appendix A.

Long term fixed platform trial

The WaveRadar REX² was deployed on Sandown Pier, Isle of Wight continuously for over one year, with remote access to the sensor to enable real-time testing and development of firmware and software options. This coastal installation was ideal for a long-term test of system ruggedness and robustness as it was a near-water situation with year-round exposure to sea spray.

The WaveRadar REX² was mounted on Sandown Pier in October 2017 and was situated 1.4 metres below an existing WaveRadar REX operated by the Channel Coastal Observatory (CCO). Annual CCO reports suggest wave conditions at this site are relatively mild: a monthly average significant wave height (Hs) of less than 0.5 m with maxima occurring during infrequent storm events. The deployment site is somewhat sheltered by a pontoon structure that creates a lagoon-like environment. The sea surface is 5-6 metres from the sensors and the pontoon introduces wave reflections into the wave field. Given the sheltered aspect of this site, the test focused on a side-by-side comparison with the adjacent WaveRadar REX and examining the long-term ruggedness of the REX².

The raw data from both WaveRadar sensors was telemetered back to RS Aqua's facility and run through the processing algorithms using WaveView Connect software, to produce a standard set of statistical wave parameters for the deployment. The dataset shows very similar activity throughout the deployment period; therefore we have focused on a single day of data to analyse. Figure 3 shows the significant wave height (Hs) parameter calculated for both sensors over a 24-hour period on the 29th of November 2019. The significant wave height present on this day is indicative of the average conditions at the Sandown pier site with Hs never rising above 0.18m. Figure 3 shows a strong correlation between the wave height parameters produced by both sensors. The mean variance between the two time-series is 0.011m. There are multiple data

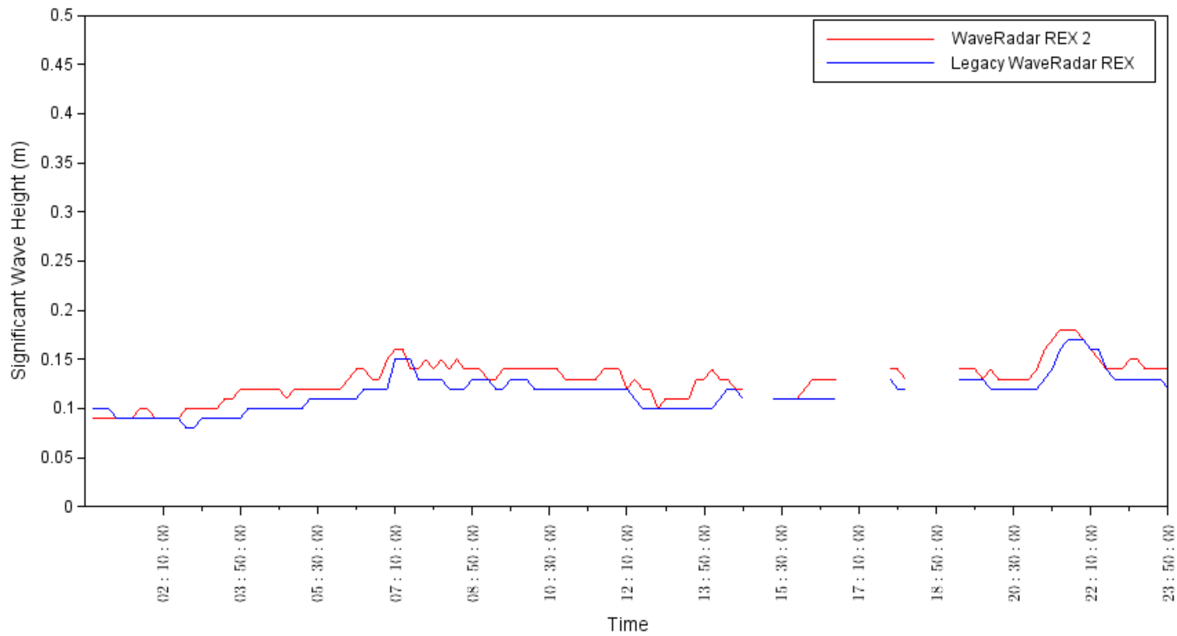


Figure 3 – 24 hours of Significant wave height (Hs) from the WaveRadar REX² and WaveRadar REX installed at Sandown Pier, 29th November 2019.

dropouts present from both sensors between 1500 and 2000 during this time period, caused by intermittent issues with the data telemetry equipment.

Whilst the REX and REX² sensors were deployed at the same site, they were not observing the exact same area of water. This alone could account for the ~1cm variation in significant wave height. However, we believe this is further complicated by the harmonics and reflection effects caused by the pontoon at the deployment site. There is also an observable phase offset of the signal. This is particularly noticeable at ~2100hrs with a steep increa se in Hs in both signals, however, there is a slight lag in the increase of the REX derived Hs. This lag equates to ~10 minutes. This lag may be indicative of a timing offset inside the data transmission and processing workflow.

Both sensors were configured to output raw data at a rate of 4Hz for this trial. The WaveRadar REX² was therefore using synchronised sampling and the data output as described at the start of this document, but the WaveRadar REX was not.

Over the course of the deployment we tested individual components and were satisfied that the WaveRadar REX² was suitably robust for use in the marine environment and offered an improvement over the WaveRadar REX which would occasionally exhibit external corrosion of the anodised aluminium components.

Stena Saga trials

In June 2019, a WaveRadar REX² was installed on the Stena Saga car ferry, which runs daily return trips from Oslo, Norway to Frederikshavn, Denmark. The majority of the ferry's route is through the eastern North Sea, and therefore conditions are typical of an offshore environment. Trials in this environment will provide a better indication of sensor performance in offshore conditions than the Sandown trial.

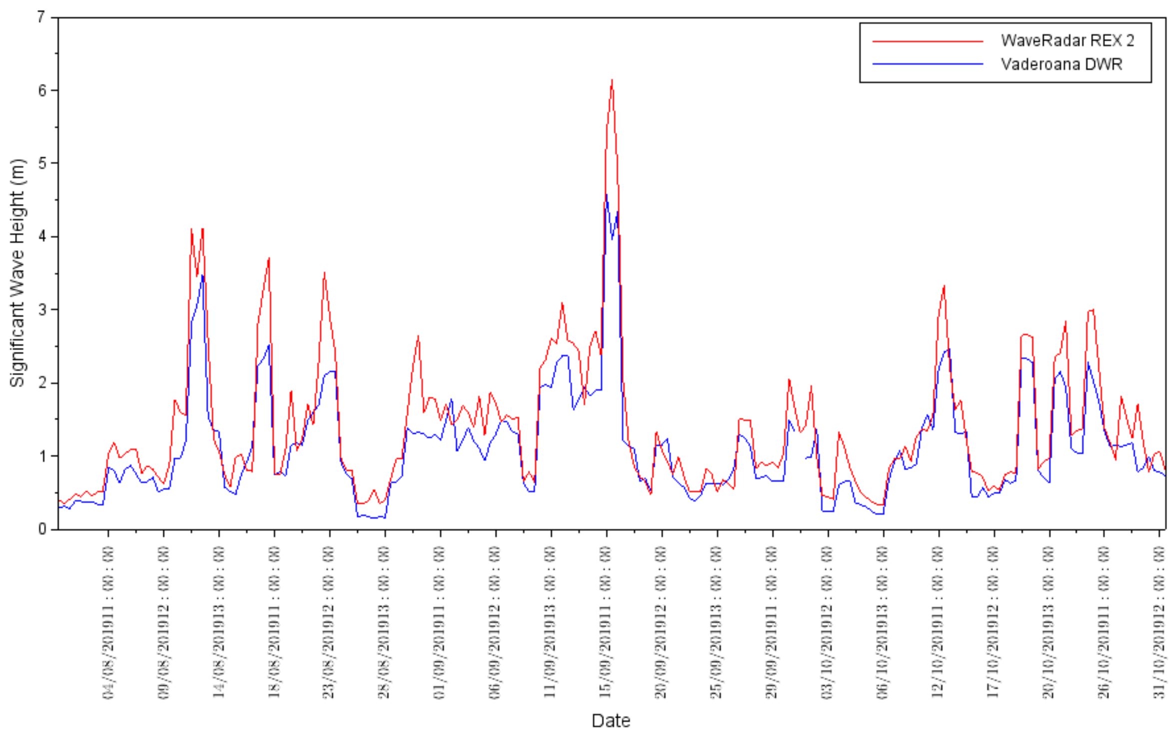
The sensor was mounted on the bridge wing on the port side of the vessel, approximately 30m above the sea surface. The raw data from the WaveRadar REX^2 was processed into statistical wave parameters using WaveView Connect software running locally onboard the ship. WaveView Connect was set up to use its motion compensation feature, thereby correcting the raw distance measurements made by the sensor by removing the effects of the vessels motion. The vessels motion was measured using a Kongsberg Seatex Motion Reference Unit (MRU). The data from the MRU was fed directly into the processing computer running WaveView Connect.

On the vessel's route between Oslo and Frederikshavn it passes within ~10km of a Datawell Directional WaveRider (DWR) Buoy operated by the Swedish Meteorological and Hydrological Institute (SMHI). This buoy is located ~20km offshore of mainland Sweden, nearby to the island of Väderöarna. The SMHI kindly made this data available to RS Aqua for comparison purposes. In this test, statistical wave parameters generated by the WaveRadar REX^2 will be compared to the parameters generated by the Väderöarna DWR buoy.

Based on the vessel track of the Stena Saga and its sailing timetable, only a three-hour period of each crossing is suitable for comparison with the Väderöarna DWR buoy. Outside of this time period, we believe the spatial variability is so great that the data no longer represent a similar wave field. Looking at solely the Väderöarna DWR buoy data, we established that the prevailing wave direction is from the West/South West. Based on this, we have assumed that only WaveRadar REX^2 data taken from Northbound crossings are suitable for comparison to the DWR buoy. This is due to shielding effects that may be present when the WaveRadar REX^2 is measuring the sea surface on the side of the vessel not facing the prevailing wave direction. When the vessel is headed north, the port side is facing West and should be free from shielding caused by the ship's hull.

Based on these assumptions we have analysed the significant wave height data for the months of August, September and October 2019. Figure 4 shows the comparison between the significant

Figure 4 – Significant wave height (Hs) from the Stena Saga WaveRadar REX² and Vaderoana Datawell WaveRider buoy. Data ranges from August to October 2019 between 11:00 and 13:00 every 24 hours.



wave height parameters produced by the WaveRadar REX^2 and the Väderöarna DWR buoy during the relevant three-hour time frame. In general, there is a good agreement between the two different sensors. There does seem to be a tendency for the WaveRadar REX^2 to over-estimate the wave height compared to the DWR buoy. The most noticeable examples of this are on the 22nd of August and the 17th of September, where the variance in Hs is ~1.5m and ~2.0m respectively. However, the mean residual between the two Hs time series is only 0.289m. A brief regression analysis of the two time series produced an R^2 value of 0.900, indicating a good fit.

Whilst there is a good agreement between the time series, there is still some variance present, particularly at higher Hs values. The most likely reason for this is the difference in deployment location. Whilst the Stena Saga does pass within 10km of the buoy, this is generally towards the middle of the three-hour period we have considered comparable. Towards the beginning and end of this period, the vessel will be considerably further away and could be experiencing markedly different wave conditions to the Väderöarna DWR buoy.

Additionally, the distance measurements made by the WaveRadar REX^2 are within a few metres of the ships hull. Whilst we have identified and tried to remove possible impacts of a shielding effect caused by the vessel, we are unable to account for possible reflected waves caused by the slab-sided hull. If reflected waves are present, they have the potential to contribute to the variation present between the two data sets.

As a further point of comparison, a legacy WaveRadar REX was mounted in the same frame, at the same location on the Stena Saga for one month in 2017. Using the same methodology as above, we conducted an analysis between the WaveRadar REX data set and the Väderöarna DWR buoy. This analysis produced a mean residual of 0.242 and an R^2 value of 0.865. Whilst the mean residual is slightly smaller for the WaveRadar REX, the R^2 value is lower, indicating less agreement between the time series. With a similar set of statistical results, an initial cross-comparison would suggest that the WaveRadar REX^2 performs similarly to the WaveRadar REX when deployed on a moving vessel.

Conclusion

The WaveRadar REX^2 has proven to be a robust and effective wave measurement sensor. Our long-term static platform trial tested its resilience in the marine environment and provided initial performance indications. The vessel-based trials built on these performance indications and provided confidence that the WaveRadar REX^2 performs to at least the standard of its market-leading predecessor. We suggest that with the new synchrony between sea surface measurement and data output, the WaveRadar REX^2 may in fact be outputting a truer immediate measurement of the observed wave profile. Further case studies of deployments on offshore, fixed and moving platforms would provide further performance validations and allow us to investigate comparisons of a wider suite of statistical wave parameters.

Acknowledgements: Swedish Meteorological & Hydrographic Institute, Stena Line, Fugro Norway, Fugro GB Marine, Channel Coastal Observatory

Appendix A - Comparison of Technical Specifications of WaveRadar REX ^{2} and legacy WaveRadar REX

	WaveRadar REX^2	***WaveRadar REX***
Performance		
Measurement Range	*3-80m*	*3-65m*
Accuracy	*3-6mm*	*3-6mm*
Sampling Rate	*10Hz*	*10Hz*
Microwave Sensor Frequency	*26GHz (open frequency)*	*10GHz (controlled frequency)*
Automated error correction	*YES*	*NO*
Warranty period		
18 months standard	*YES*	*YES*
3 years extended	*YES*	*YES*
5 years extended	*YES*	*NO*
Data & Power		
Output Data Rate	*2-10 Hz (user configurable)*	*2-10 Hz (not user configurable)*
Data Output Frequency	*RS485*	*RS232*
USB & Ethernet Output Option	*YES*	*NO*
Power Supply	*9-36 VDC*	*10-28 VDC / 220-240 VAC*
Power Consumption	*average 0.4W, peak 1W*	*10W*
Software Options		
WaveConfigurator set up software	*YES*	*NO*
WaveView Connect processing software	*YES*	*YES*
Motion Compensation system for moving vessel installations	*YES*	*YES*
Hardware		
LCD sensor display	*YES*	*NO*
Field Bus Modem required	*NO*	*YES*
Construction	*SS316 & PTFE*	*Anodised aluminium & PTFE*
Weathershield	*YES*	*YES*
Dimensions		
Weight: sensor / packed ~	*9kg / 15kg*	*26kg / 45kg*
Size: sensor / packed ~	*25x25x37cm/40x40x55cm*	*45x45x65cm/80x80x60cm*
Certifications		
Europe - E1 ATEX Flameproof	*YES (FM15ATEX0055X)*	*ATEX/IECEx*
USA - E5 Explosionproof (XP)	*YES (FM-US FM16US0010X)*	*ATEX/IECEx*
Canada - E6 Explosionproof	*YES (FM-C FM16CA0011X)*	*ATEX/IECEx*
International E7 IECEx flameproof	*YES (IECEx FMG15.0033X)*	*ATEX/IECEx*
RoHS compliant lead-free PCBs	*YES*	*NO*
Low cost uncertified version	*YES*	*NO*