Comparison of Directional WaveGuide Radar with Directional WaveRider Buoy

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Abstract

Down looking FMCW radars for measuring water level, tides and wave height have been in use for 25 years. A combination of three down looking FMCW radars, mounted on an off shore location, can be used to accurately measure ocean wave height and wave direction. At locations where an offshore mounting construction is readily available, the major advantage of this relatively new technology lies in the contact free measuring technique. As a result, the technology provides a maintenance free solution to obtain valuable oceanographic information.

This paper presents a comparison study between the Radac Directional WaveGuide and the Datawell Directional WaveRider Buoy. Experimental data was obtained at the Princess Amalia Wind Park situated off the Dutch coast near IJmuiden.

The results show that both measuring techniques compare well with each other. It is concluded that this setup of three down looking radars is a technically sound solution for measuring both wave heights and wave direction.

Keywords: Wave Sensor, Wave Height, Directional Wave Measurement

1. Introduction

Over the past 30 years the standard for wave directional information is set by wave directional buoys, e.g. Datawell's Directional Waverider. The main advantage of using a buoy is its independence from support structures. Disadvantages of this method are high maintenance costs and the risk of long periods without measurements when a buoy breaks from its mooring or runs out of power.

From references [1, 3, 2] it is known that wave directional information can be obtained from an array of wave height sensors. Experiments are described in literature but operational experience has hardly been acquired. The idea to make an array of radar sensors into a commercial product came up 15 years ago. Shortly after the Wave Directional Radar Array experiment was started. The WaDiRA experiment was a joint cooperation between the Dutch Government (Rijkswaterstaat), The Marine Research Institute (Marin), The Institute of Applied Physics (TNO/TPD) and Radac. The experiment revolved around two main topics:

- In situ measurements on Meetpost Noordwijk with an array of three radar level gauges and a Directional Waverider used for reference purposes.
- Simulation experiments to obtain the properties of the array in different sea state conditions.

In chapter 2 some of the experiment results from reference [4] are discussed.

Down looking FMCW radars for measuring water level, tides and wave height have already been in use for 25 years. They have shown to be robust and they are practically maintenance free. A previous study reference [5] has shown that the wave height information from the WaveGuide radar and Datawell's Directional Waverider are statistically identical.

The main conclusion of the WaDiRA report was that an array of three down looking FMCW radars placed in an equilateral triangle with ca. 6[m] long sides is optimal. In practice it appeared to be rather difficult to find three positions on a platform to fulfill this requirement. By tilting one or two radars their footprints at the water surface can be shifted towards this optimal configuration. This improves the installation process but has also its drawbacks. Radac supports three types of configurations, called the space, line and one point array. These three configurations and their design criteria are described in chapter 3.

Wave information was needed to support the operation of the offshore "Princes Amalia Wind-Park". The wind-park is situated 25[km] away from the Dutch coast. Based on good faith and a strong sense of cooperation Radac could install two

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WaveGuide radar arrays (in the line array and the one point array configurations) on the transformer platform in the middle of the park. A fiber optic link connects both systems with the Radac office. Once the systems were fully in operation the needed validation of the information could take place. A Datawell Directional Waverider was deployed 200[m] away from the transformer platform. Details of this experimental setup are described in chapter 4.

Several techniques exist for measuring wave directions but comparing their results is not a trivial task. Each technique has its pro's and con's. In chapter 5, the chosen method for comparing the measurements obtained from the Directional WaveGuide and the Directional Waverider is discussed.

In chapter 6, the measurements are described and the main parameters (significant wave height Hm0 and mean direction Th0) are given for the chosen period of analysis. The high correlation between both systems for wave height information as already described in reference [5] is once again demonstrated.

In chapter 7 the directional information is investigated in more detail. A three hour period is chosen, that is characterized by the passage of a depression that causes turning winds. This period is used to demonstrate the capabilities of the systems on the base of a detailed frequency spectra analysis.

The final conclusion is that, for operational and engineering purposes the directional WaveGuide is a reliable and maintenance-free option.

2. Previous work WaDiRA

A **Wa**ve **Di**rectional **R**adar **A**rray experiment was initiated by the idea to make an array of radar sensors into a commercial product. The WaDiRA project was a joint cooperation of the Dutch Government (Rijkswaterstaat), The Marine Research Institute (Marin), The Institute of Applied Physics (TNO/TPD) and Radac. The project consisted of two main topics:

- In situ measurements on Meetpost Noordwijk with an array of three radar level gauges and for reference purpose a Directional Waverider buoy.
- Computational analysis of simulated data to estimate the performance of the array in different sea states.

The report on this WaDiRA experiment is available. Here only some conclusions are given.

2.1. Measurements

- With the three radar level gauges used in the applied radar array good quality information has been obtained for all sea states that occurred during the experiment. The sea state during the experimint covers the frequency range from 85 up to 500[mHz] and wave heights of 25 to 550[cm] from different directions.
- Good quality information has not only been obtained by radars pointing vertically downward but also by radars radiating towards the sea surface under a slant angle (approx. 10°[deg] from vertical). Simulation and additional measurements will have to clarify how this information from tilted radars can be processed optimally. The advantage of radars mounted close to each other and mounted with a slant angle is evident for applications both on fixed platforms and on ships.

2.2. Triangular Array Configuration

- Sensitivity analysis shows that the radars function best when placed in an equilateral triangle.
- In order to measure high-frequency waves correctly the dimensions of the array should not be too large. Both measurements and simulations show that a radar array with 3[m] long sides is optimum for measuring wave direction of waves with wave frequencies of up to 500[mHz].
- According to the simulations, there are no restrictions on the low-frequency side with regard to array dimensions. But since a low frequency period did not occur during this experiment, further investigation is required.

2.3. Processing Methods

Four processing methods have been investigated.

- With all four recent operational processing methods wave height and mean direction can be defined properly. The results are less favorable when it comes to wave directional spreading. These are still over-estimated by all methods.
- The slope method functions well for both low and medium frequencies, but are limited for higher frequencies (> 200[mHz]). Making the array equilateral and reducing its size offers some improvement, but is still not sufficient with regard to defining the directional spreading.

3. Array configurations

From the WaDiRA project it was concluded that the optimal configuration is formed by an equilateral triangle with 6[m] long sides. This array size is optimal for wave lengths of 18 to 180[m], hence wave periods of 3.4 to 10.7[sec].

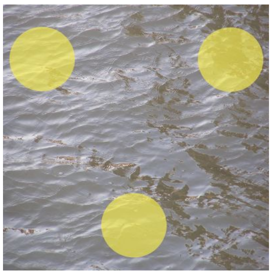

Figure 1: Visualization of radar beam footprint on the water surface.

Often it is difficult to find three positions at the platform that fulfill the array size requirement. The positions of the radars do not determine the shape of the array but the positions of their footprints. The footprints can be shifted by tilting the radar.

This allows the positioning of the radars in line along one side of the platform and tilting the middle radar. Or positioning the three radars at one position and tilt two radars. It is concluded from experiments that the reflection strength decreases rapidly when tilting the radar more than 15°[deg].

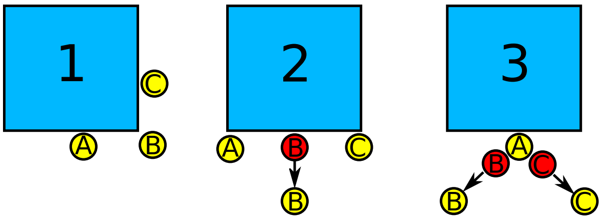

Figure 2: Different possible configurations for radar arrays.

Radac supports three configurations shown in Fig. 2. The first configuration, is the space configuration with three radars A, B and C facing vertically downwards. The second configuration, is the line array with the radars A and C facing downwards and radar B tilted from 10° to 15°[deg] in the direction perpendicular to the line formed by radars A and C. The third configuration, is the point array with radar A facing vertically downwards and radars B and C tilted from 10° to 15°[deg] away from the vertical and in directions ±30°[deg] away from the normal to the platform. The space configuration, was well investigated in the WaDiRA project. The performances of the line an point configurations are described in this report.

Figure 3: Radar A looking perpendicular downward. Radars B and C tilted by 15°[deg].

To create a triangle with the right sizes the radars have to be mounted sufficiently high. For instance a point array with size of 6[m] requires a mounting height of at least 25[m]. A line array configuration requires a mounting height of at least 20[m].

Figure 4: Aerial view of Princes Amalia Wind Park.

4. Experimental setup at the Prinses Amalia Wind Park

An experimental setup was build at the Prinses Amalia Wind Park (PAWP). The PAWP is located 25km off the Dutch coast as shown in Fig.5.

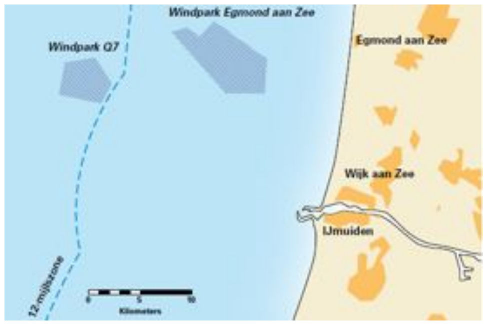

Figure 5: Location of Princes Amalia Wind Park (denoted by Windpark Q7) in the North Sea off the coast of IJmuiden.

At the transformer platform (OHVS) in the center of the park two Directional WaveGuide Systems are installed, one with the radars in a point array configuration and one with the radars positioned in 4[m] intervals and forming a line array configuration. The line array is part of the standard PAWP instrumentation and the Point Array was added for the purpose of this research. In August 2013 a Directional WaveRider buoy was deployed at 200[m] distance north/west of the OHVS platform. The receiver for the buoy was installed at the OHVS. The data used for the current work was gathered between January and May 2014.

Figure 6: Radac Directional WaveGuide in Line Array arrangement.

5. Comparison Considerations

It would be ideal to measure how the wave energy is distributed over all frequencies and over all directions. However, this is not achievable by any available sensor.

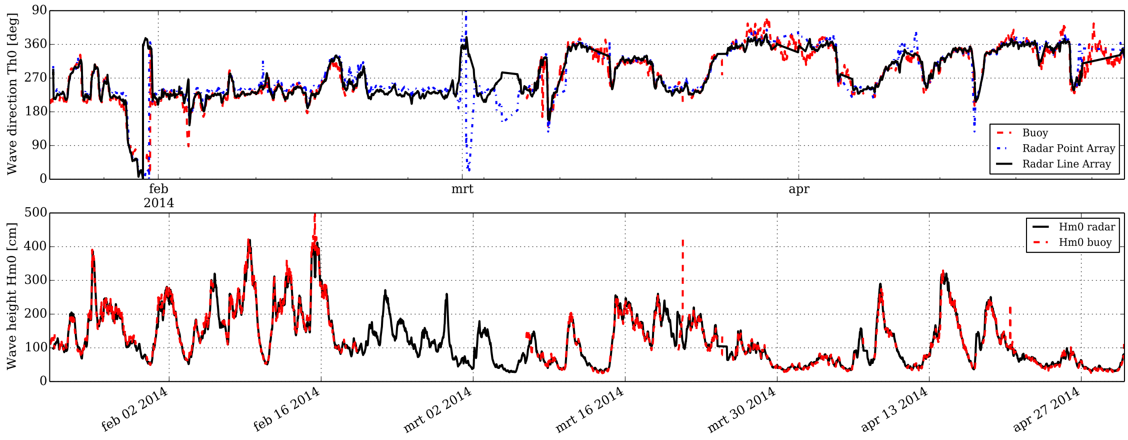

Figure 7: Comparison of directional wave data (top) and parameter Hm0 (bottom).

The existing measurement techniques use different sensors that measure different properties of the water. For example, the Directional Waverider measures three accelerations at one point during a long period. While, the systems based on navigation radars use the position of wave crests in a larger area during a shorter time. Hence, the calculated parameters are defined differently. Reference [6] describes these issues.

Both the array of down looking radars and the Directional Waverider are so called single point systems. The basis of their wave directional processing is the two dimensional Fourier transformation from time/space domain to frequency/directions domain. The Directional Waverider measures the time series of three displacements (Vertical, North-South and East-West). The Directional WaveGuide measures the time series of three vertical displacements (translated to one vertical displacement and two slopes). This processing method results in a high resolution of frequency (5[mHz]) but in a poor directional resolution (4 Fourier coefficients).

From the four Fourier coefficients obtained, the first four moments of the directional distribution function can be calculated. These are mean direction, spreading, skewness and kurtosis. In practice only the mean direction and the spreading are used.

So both systems use the same method of analysis. But there is a difference in bandwidth. The Directional Waverider measures at a single point. While the array is larger and is not able to measure the shortest waves. These short waves have to be filtered away otherwise they are under sampled in the space domain. A wave with wave period of 2[sec] and a wave length of 6[m] can not be reconstructed from measurements every six meters.

For comparison the mean wave direction parameter in the frequency band from 30 to 500[mHz] (2 to 33[sec] waves) is used. This is not correct as for the array the higher frequency part is not relevant. If there is significant energy at those higher frequencies it has influence. For the wave height information this low pass filtering is not applied as only one radar is used for the wave height information.

6. Results

6.1. Three Month Period

The mean wave direction (Th0) and the significant wave height (Hm0) over the period between January 22nd and April 30th are shown in Fig. 7. Looking at the wave direction it is observed that in general there is a good agreement between the three devices.

The wave height information from the WaveGuide systems and the Directional Waverider buoy are in perfect agreement with each other as already described in the wave height comparison study from 2005. The significant wave height measured with the Directional Waverider shows some spikes. These spikes are known and occur mostly in storm conditions (further explanation can be found in reference [7].

The comparison of the mean direction parameter Th0 shows in general a good agreement between the three systems. To interpret the results some remarks have to be kept in mind.

- First of all the mean direction is really a mean direction. If there are two wave fields with the same distribution of the energy over their frequencies but with a different direction the mean direction measured will be in the middle of the two wave filed directions.
- The tidal range which is in this case approximately 1.2[m], causes the array size to vary with the water surface level. In this case the effect is not large enough. But for locations with a lower mounting height and/or larger tidal range the effects of changing array size must be taken into account.
- Due to the wave motion the distance to the water surface varies. For the tilted radars this causes a shifting horizontal position of the footprint at the water surface.
- Tilting the radar also causes a weaker reflection from the sea surface especially for calm weather. So more noisy signals can be expected from the tilted radars.

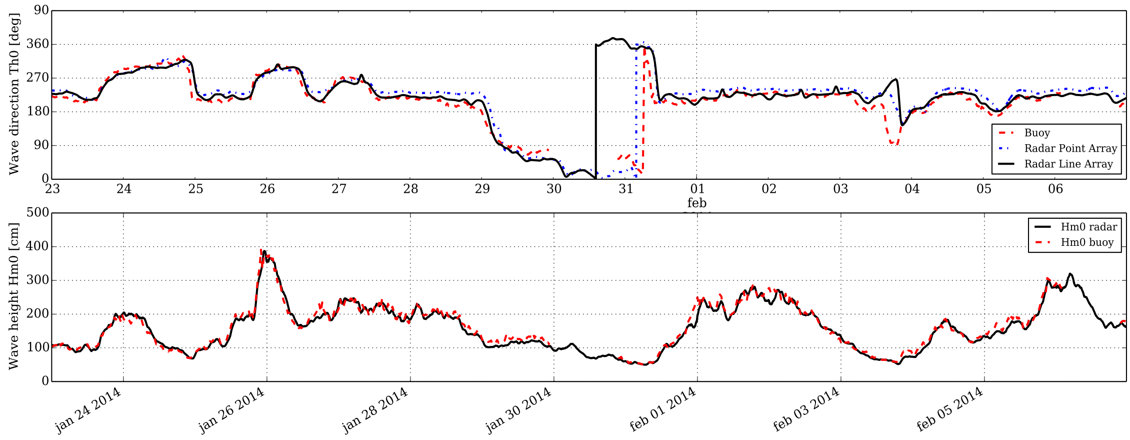

Figure 8: Zoomed in comparison of directional wave data (top) and parameter Hm0 (bottom).

In Figure 7, it can be seen that the main fluctuations in the mean directions are followed by all three systems. It is clear that for very low sea states (e.g. March 1st) the one point array gives a more noisy parameter. For more detailed information we first zoom into a two weeks period starting on January 23rd.

6.2. *Two Week Period*

In the two weeks period from January 23rd to February 6th several wave regimes occur as shown in Fig. 8. On average the wave heights are higher than 1[m] and coming from Southwest. On January 24th Northwestern winds cause waves of 2[m] high from the Northwester direction. similar conditions occurred on January 25/26th but with wave heights of up to 3.5[m]. On January 31st and February 1st the wind slowed down and turned East causing waves lower than 0.5[m] coming from the Northeast.

It can be seen that the line array and the Directional Waverider are in good agreement. The one point array has for the Southwest directions a deviation of ca 10 degrees which is not the case for the Northwest and North directions.

6.3. *Two and A Half Hour Period*

For more details a 3[h] period from January 25th is examined. Figures 9 to 13 show the wave height spectra and mean direction spectra at 30[min] intervals from 19:00 to 21:30 on January 25th. At 19h00 the wave height was 1[m] with the mean direction for all frequencies from Southwest. At each step it can be seen that a wave field coming from Northwest is growing in wave length (towards lower frequencies) and in wave height. At 21:00 the mean wave direction is for all frequencies around 300°[deg] and the wave height is approximately 3.5[m].

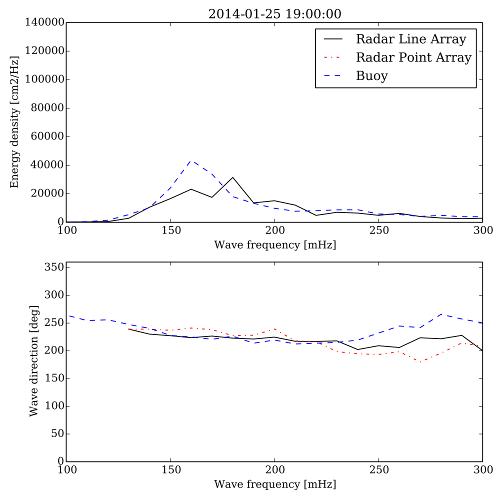

Figure 9: Comparison of directional wave data.

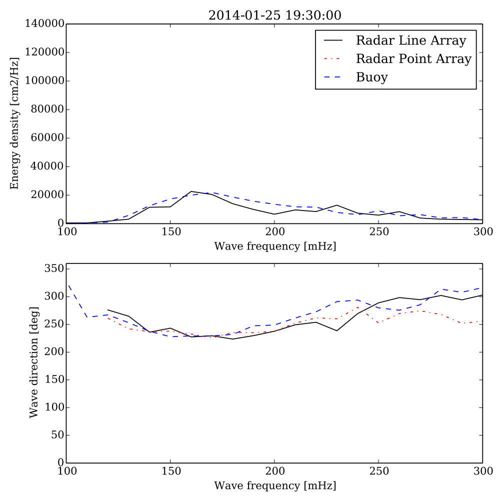

Figure 10: Comparison of directional wave data.

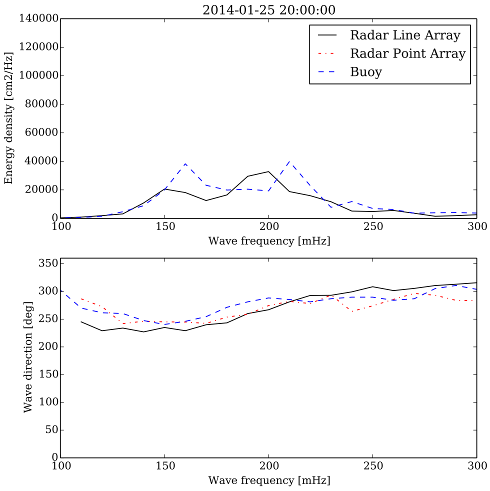

Figure 11: Comparison of directional wave data.

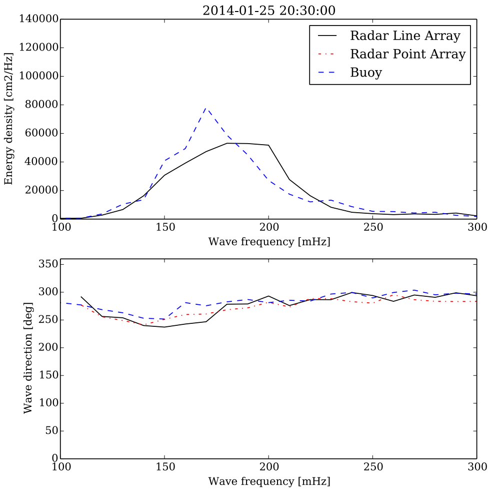

Figure 12: Comparison of directional wave data.

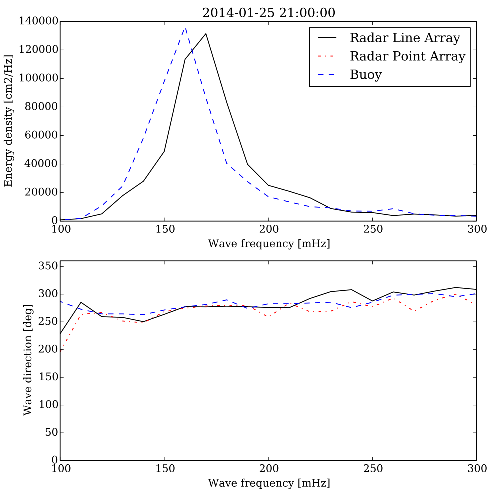

Figure 13: Comparison of directional wave data.

7. Conclusion

It is possible to measure wave directions reliably using an array of three WaveGuide Radar sensors. With regard to the quality of information the space array configuration is preferred. If this configuration can not be used the line array or the point array can be used as alternatives. The maximum tilt angle of the radar can be 15°[deg] from vertical. The mounting height should be at least four times the array size. The array size limits the wave lengths that can be measured. It is found that waves can be measured best in the range from 3 to 30 times the array size. As wind waves and swells have wave lengths in the range from 10 to 250[m] the array size should be somewhere between 3 and 8[m]

Tilting the radars causes a reduction in signal strength and therefore some more noise in the measurements. For the mean wave direction parameter the effect is minimal. The mean wave direction parameter is most relevant for operational use.

In this study it has been shown again that the WaveGuide Radar and the Directional Waverider produce the comparable results for both wave hight and wave direction.

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